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Making mini speakers

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Using and interfacing an EEPROM iButton

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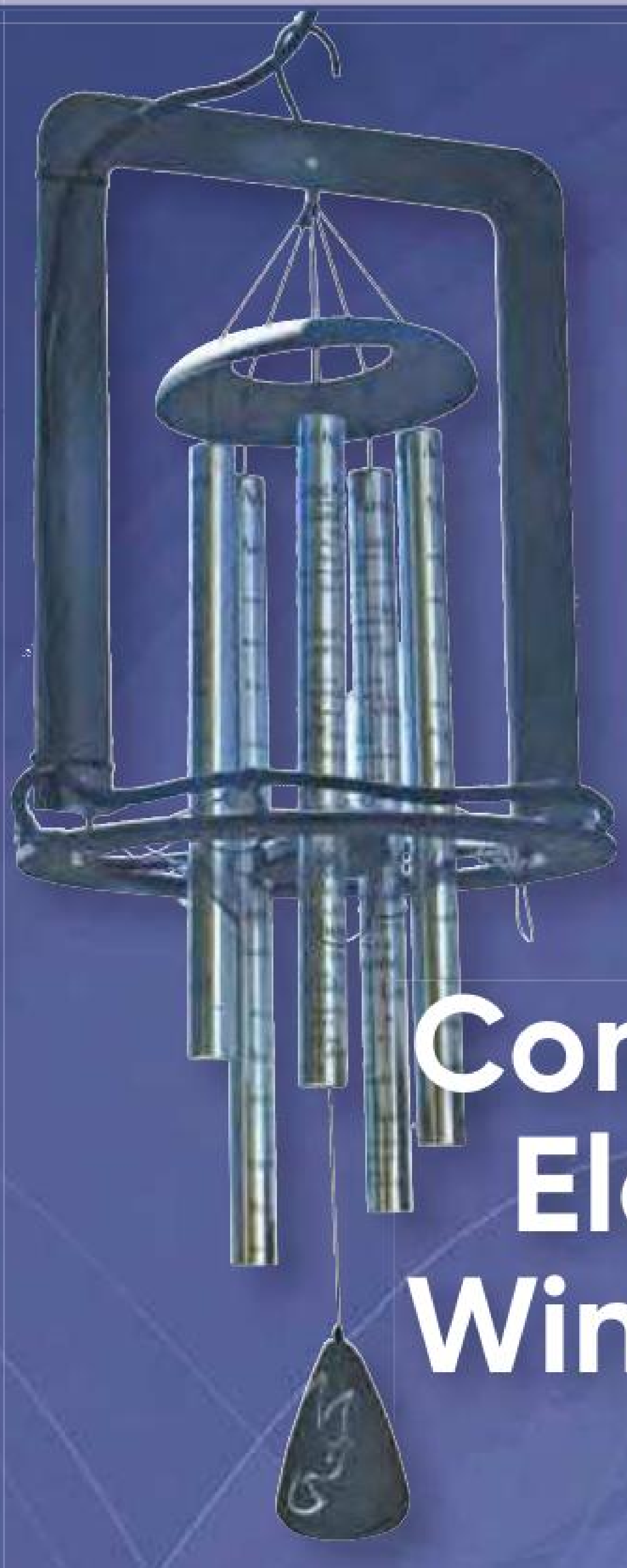

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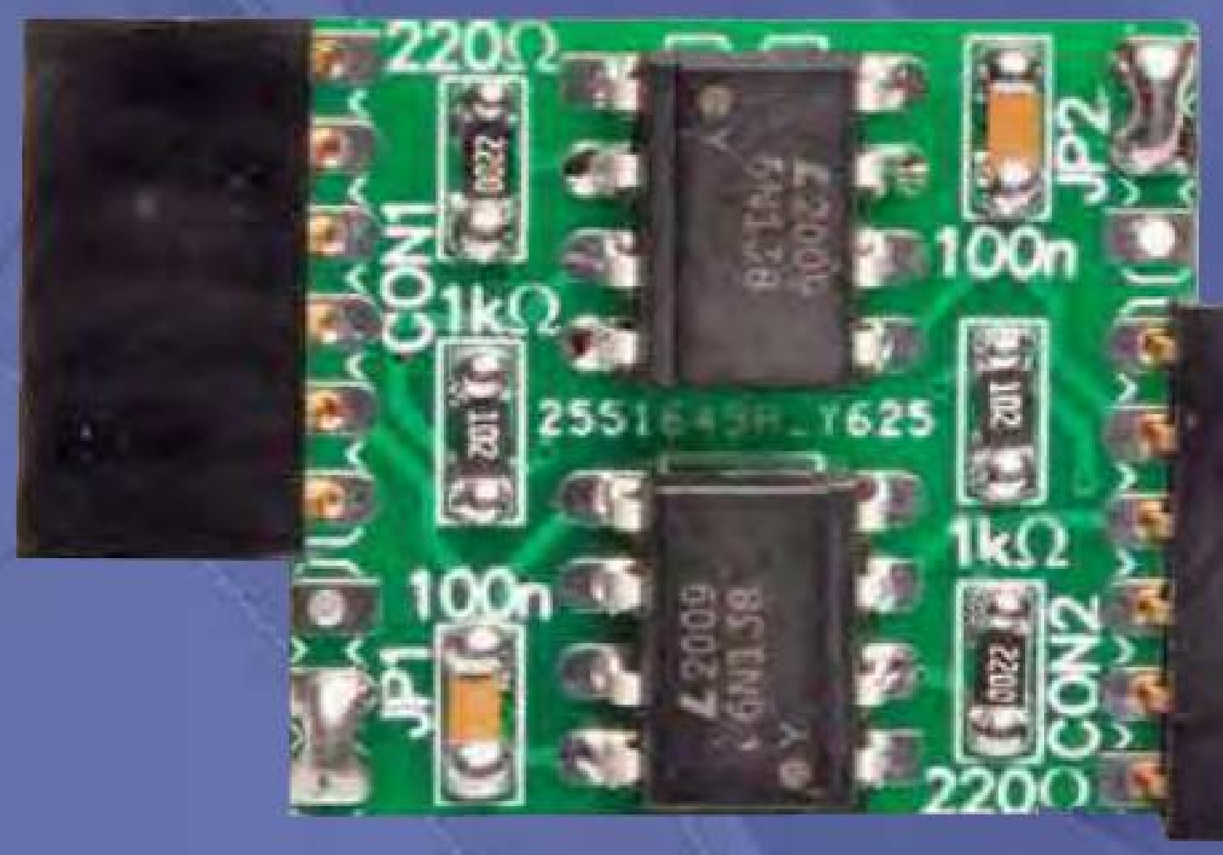
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WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

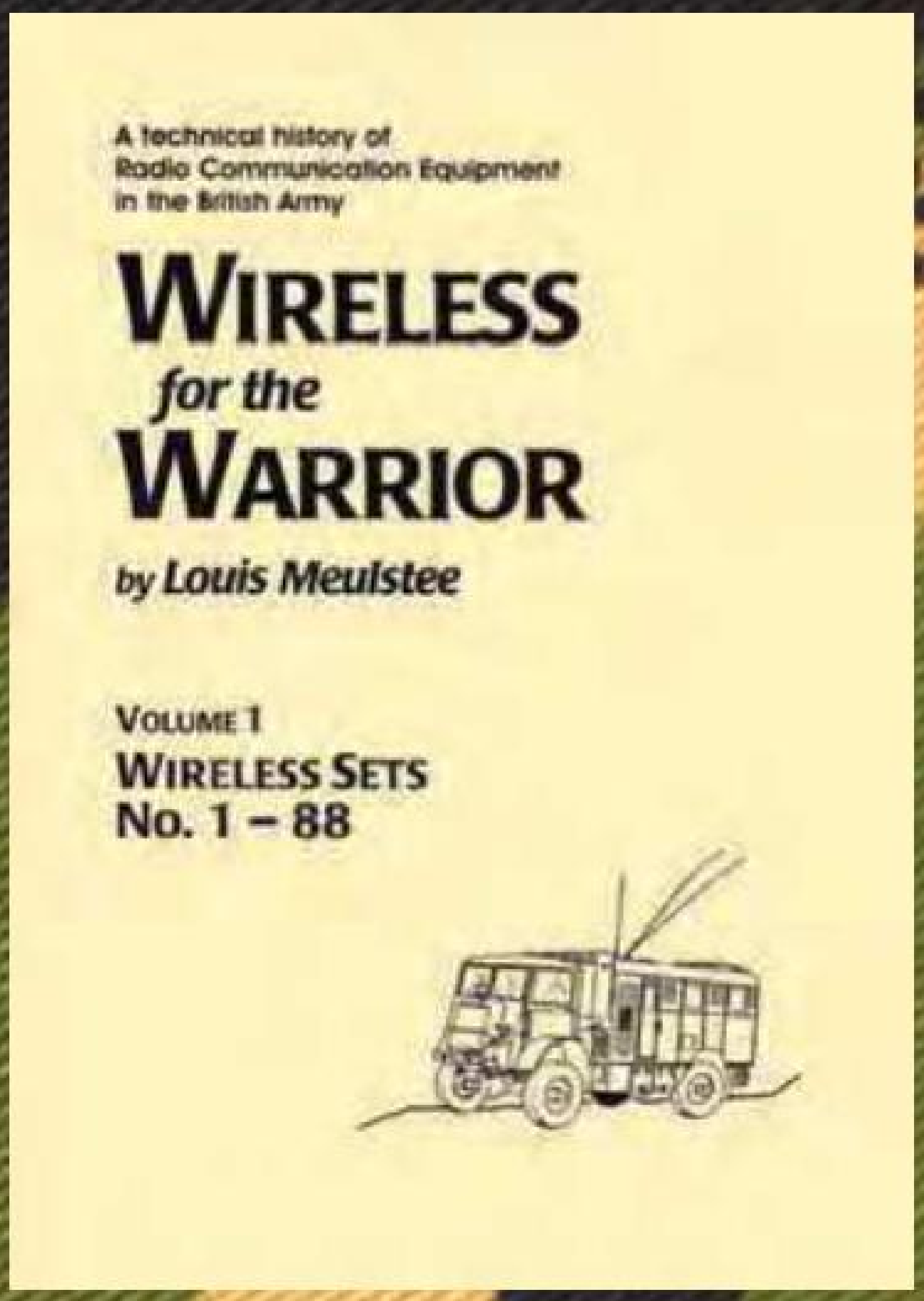
The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

The books are very detailed and include circuit diagrams, technical specifications and alignment data, technical development history, complete station lists and vehicle fitting instructions.

Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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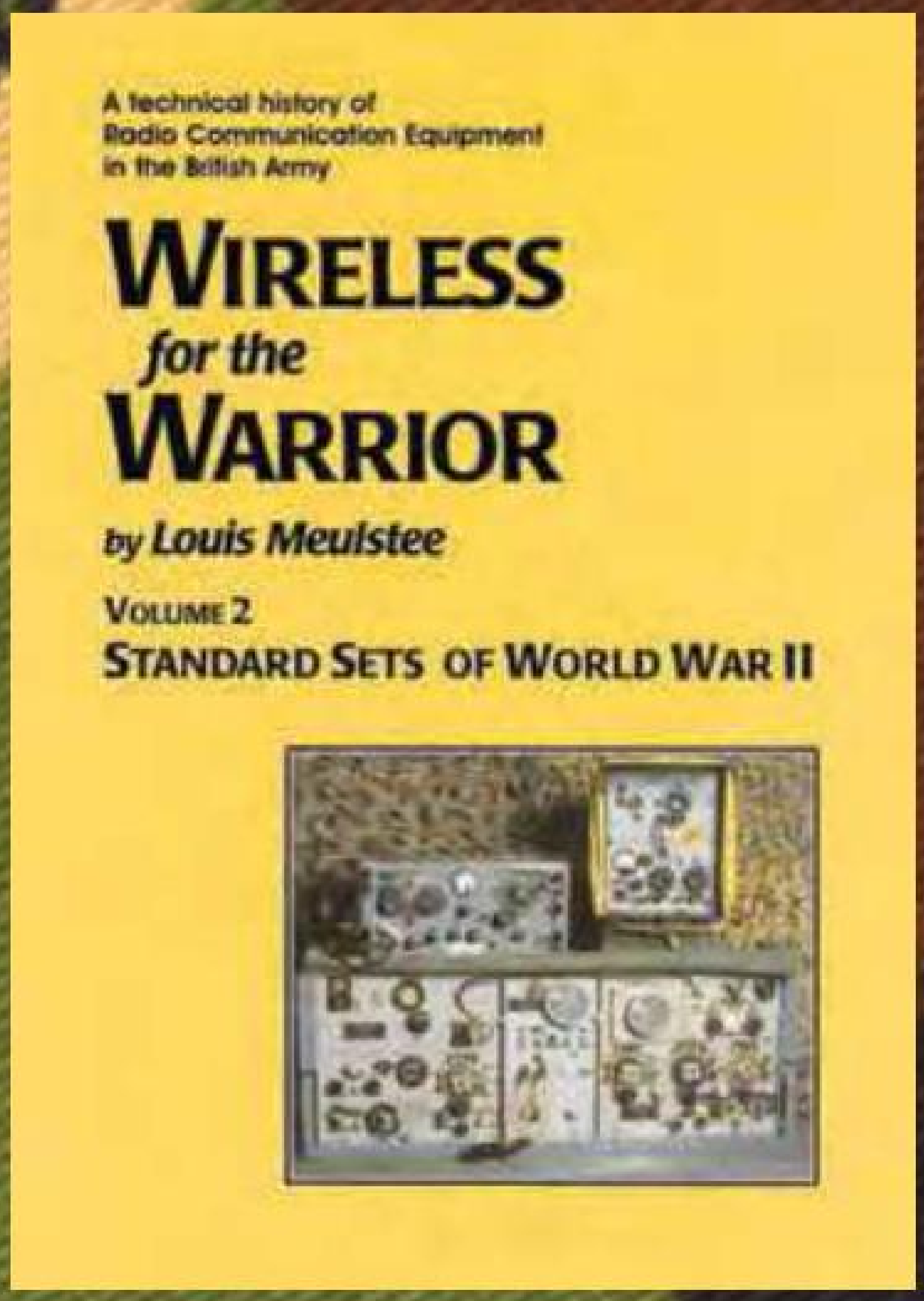

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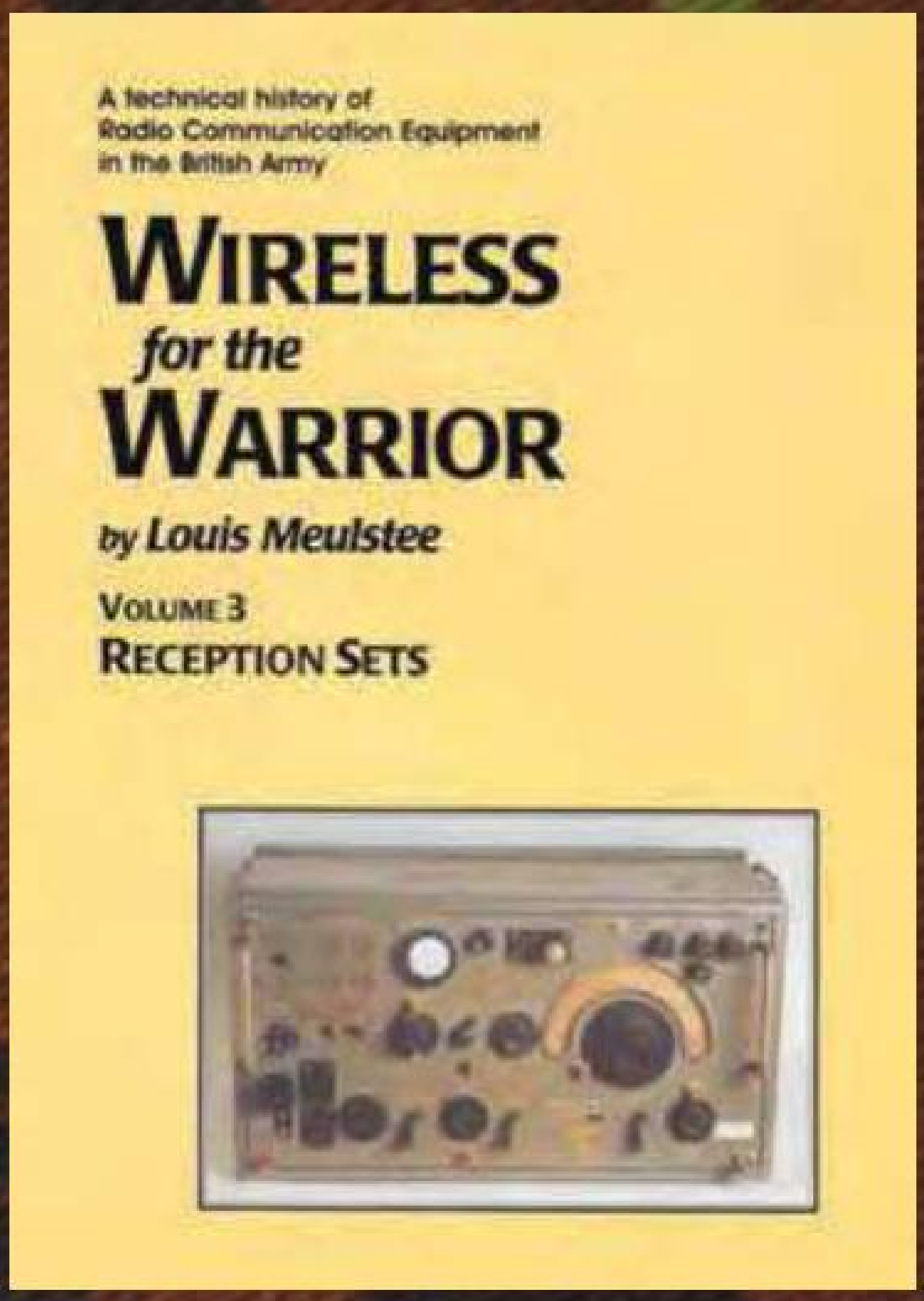

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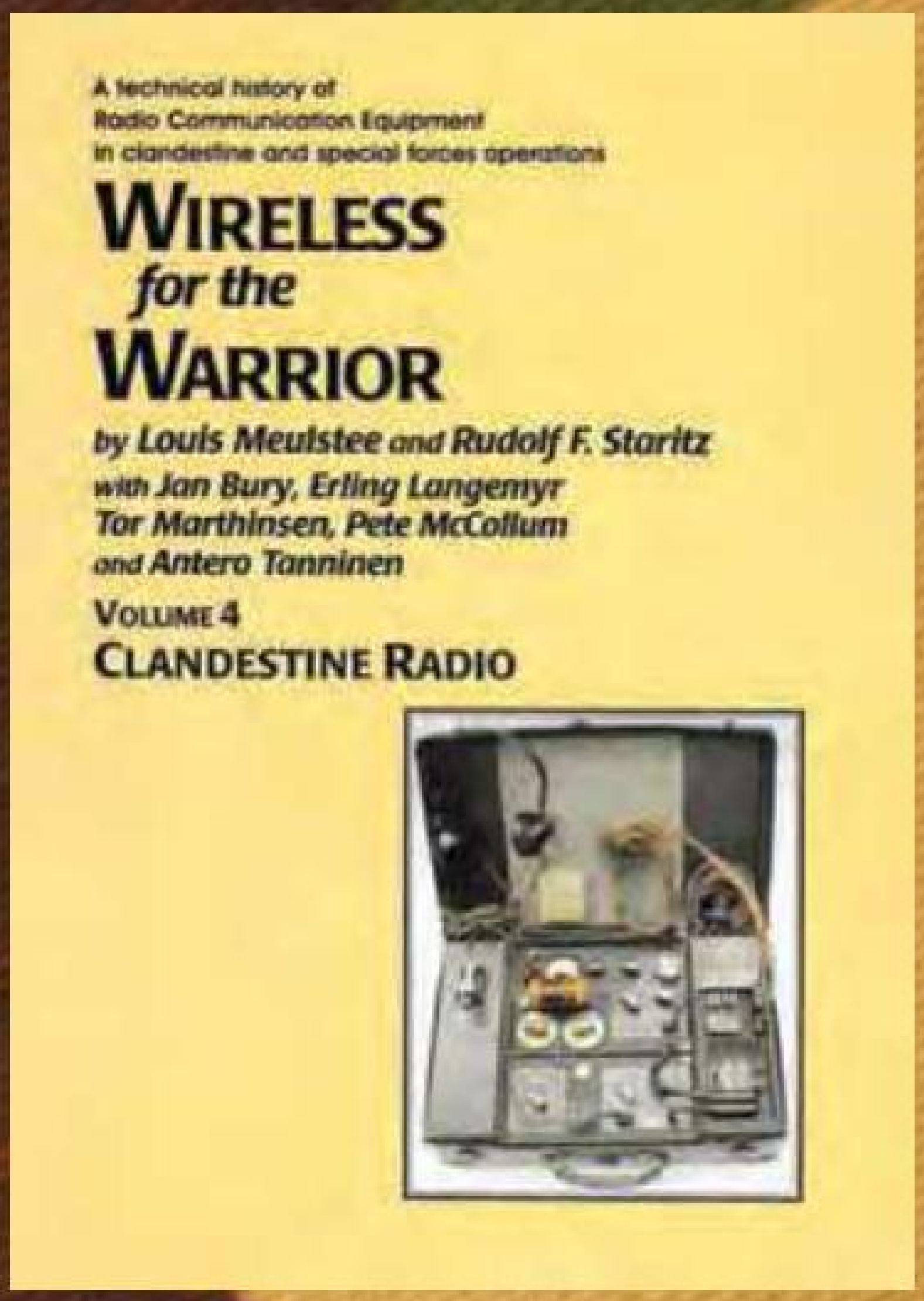

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in clandestine and special forces operations
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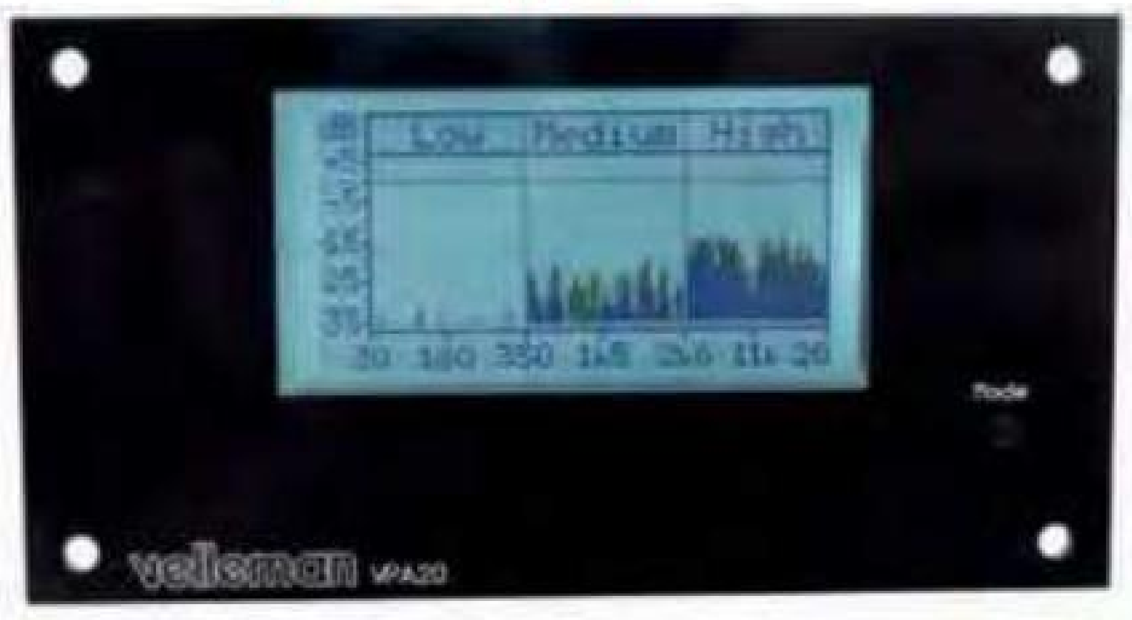

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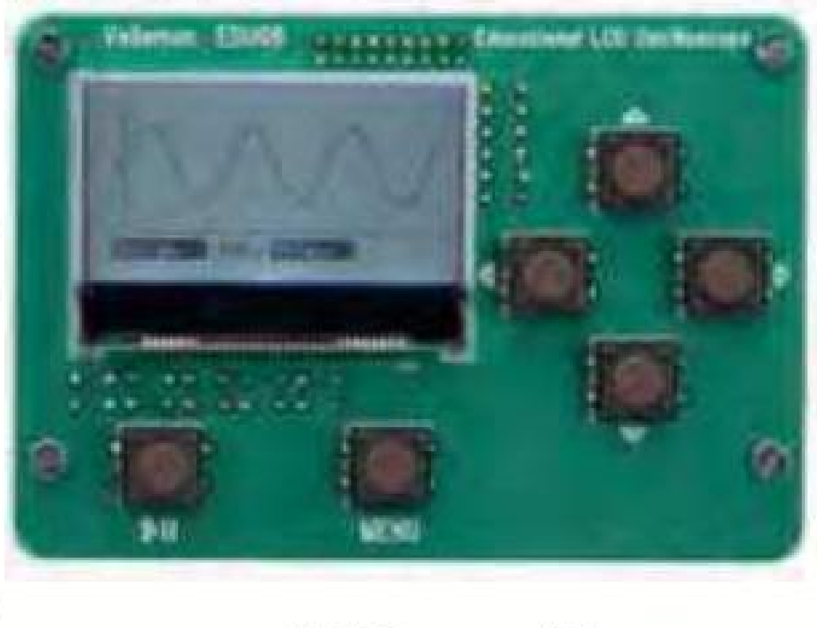

Build your own LCD oscilloscope with this exciting new kit. Learn how to read signals. See the electronic signals you learn about displayed on your own LCD oscilloscope. Despite the low cost, this oscilloscope kit has a lot of features found on expensive units like signal markers, frequency, dB, true RMS readouts and more. A powerful auto-setup function will get you going in a flash!
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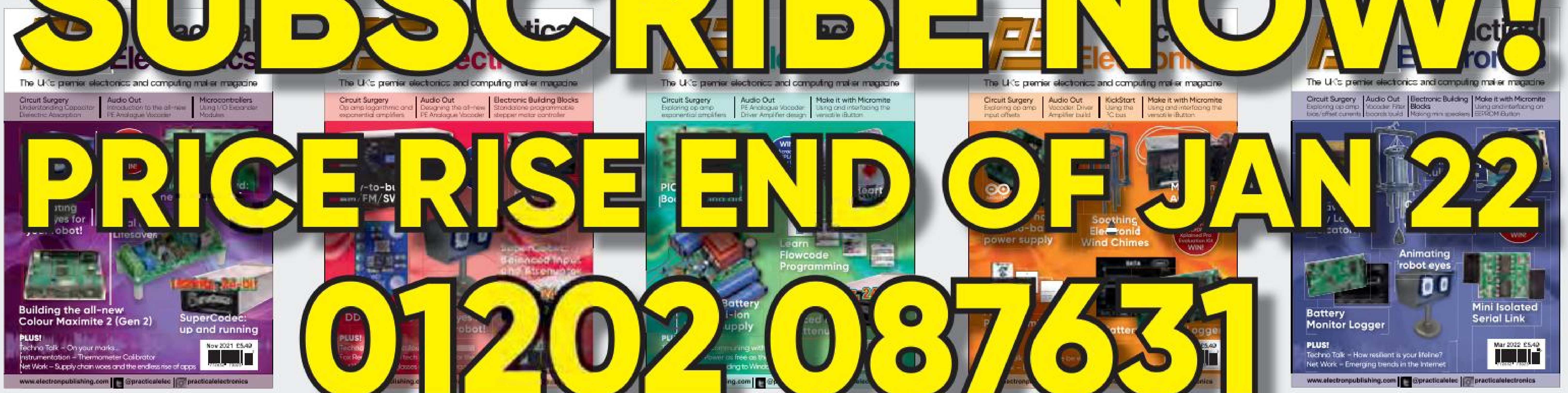

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A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

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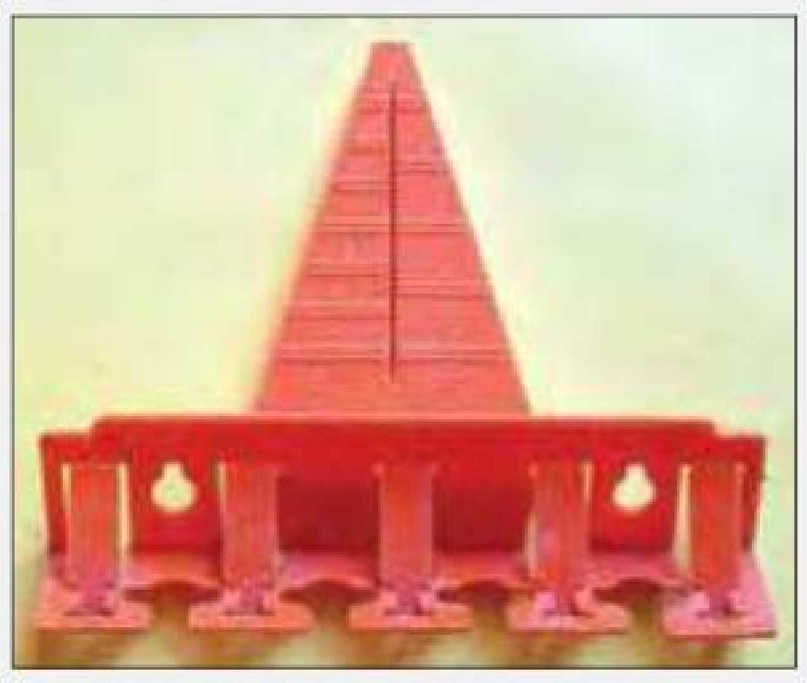
Something for everyone

Welcome to the March 2022 issue – another packed magazine with something for readers of all levels and interests. I do get asked from time to time why there are so few projects for beginners. It's a good question, and I suppose the answer is the one all editors fall back on – there's only so much space in each issue. However, I do understand that electronics can be a bit intimidating for beginners and some of our larger, more involved projects do require experience and knowhow. With that in mind, this month we have a couple of nice projects that should appeal to readers just starting out in electronics. The *Busy Loo Warning* design has many uses – not just the one on the tin – and is an excellent introduction to project building. Likewise, Julian Edgar's *Laptop Speakers* article demonstrates that you don't need super expensive drivers and an apprenticeship in joinery to make a good, simple pair of speakers. Both of these projects are thoroughly recommended.

Blast from the past – Part 2

In the February issue, I asked if anyone remembered – or even kept – some of the 'giveaways' that used to be supplied with *PE*/*EE*/*EPE*. What a great response! – I don't have the space to thank all of you personally, but I particularly enjoyed hearing from Mike Cowlishaw (Constructor's Guide and wire-bender template); Ashley Cundy (green *PE* PCB/pin-out ruler plus two other goodies); and Mike Hill, who wrote, 'I've never used the tool rack (Patent Pending!), but the wire-bending gauge for use with perfboard must be the most useful free gift ever. It is dated 1976.'
I don't think I've seen Mike's wire-bending gauge before, but it's a great idea – see the orange 'triangle' below. Perhaps someone could resurrect it with a 3D printer?



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Looking for a job in the Isle of Wight?

Last, we take the occasional job ad, and this month there is an opportunity in the Isle of Wight – see page 17. I only mention it here because I went on holiday there a couple of years ago and it's a fabulous place. Have a look if you want to combine electronics with a beautiful location in southern England.

Keep well and stay healthy

Matt Pulzer
Publisher

How resilient is your lifeline?

Techno Talk

Mark Nelson

You would expect the upgrade of a vital public utility to improve the dependability of the one it supersedes. But if you had in mind your telephone and broadband services, forget it. Unless current policy is changed, you'll be horribly disappointed.

By the time you read this article, the appalling weather and lengthy power cuts affecting northern Britain in late November and early December last year should be no more than a memory. Troops had to be called out after hundreds of thousands of homes were without electricity, some for over a week, after Storm Arwen brought down power lines in what was called a 'once in 30 years' event. Many homes, schools and other organisations were without telephone, mobile or broadband communication too.

Nationwide isolation

This mayhem was the result of extreme weather conditions and fortunately, they affected only some parts of the country. However, under the planned replacement of the existing analogue network, telephone and broadband users across the whole country are likely to suffer the same kind of isolation whenever a power cut lasting more than an hour or two takes place, possibly even sooner. OFCOM, the UK telecomms regulator appears to be unconcerned, with its website blandly advising: 'Over the next few years, it will become more common for phone calls to be carried over broadband, and this will eventually replace traditional landline call services. Whether you have a corded or cordless landline telephone, broadband-based call services need mains power to operate.' 'Eventually,' means in 2025 (only three years away) and already many customers have had their telephone service transferred onto broadband.

Necessary measures

The website (**https://bit.ly/pe-mar22-ofc**) continues: 'Providers must take all necessary measures to ensure their customers can call the emergency services during a power cut'. So, these companies will need to put additional protections in place as they move to new broadband-based call technology. Sounds reassuring? Hardly, because OFCOM's obligation on service providers (**https://bit.ly/pe-mar22-ofc2**) mandates merely that providers should have at least one solution available that enables access to emergency services for a minimum of one hour in the event of a power outage in the premises. Yes, you read that correctly: one hour. But take-up of the 'solution' is optional from the subscriber's point of view. Also, there has been no announcement on whether the street cabinets, where the optical signals are demultiplexed into individual fibres into premises, will have back-up batteries, and if so, for how long these will last. Is this taking 'all necessary measures'?. Not in my book.

When your phoneline is converted to run over broadband (known as VoIP, Voice over Internet Protocol), it includes the supply of a new modem from your telephone service provider, and this is what requires back-up power. BT calls this new system 'Digital Voice'. You may well have a mobile phone and yes, you may be able to use this instead of your landline phone in a power cut situation. But only as long as the mobile's battery lasts out; then it's as dead as a dodo until the juice is restored. Moreover, the power cut may well affect the cellular base station that your mobile 'talks to', so you cannot rely for certain on the mobile as your lifeline. It goes without saying that the Internet won't work at your premises in a power cut either, as it runs over the same broadband fibre as the new telephone service.

Lies, damned lies and statistics

Of course, the harm done by a power cut depends on how long it lasts. Anecdotal and personal experience indicate an outage is usually either less than 15 minutes or else six hours or more. Statistically, the average cut in the UK varied between 30 and 51 minutes in 2021 (it varied according to where you lived). But this is both meaningless and misleading. We need to know whether this 'average' is in fact the figure occurring most frequently, the central value in the list from shortest to longest or the total of all the values divided by the number of values; each of these figures will differ. Nor does the number of outages reported tell us how large a proportion of consumers would be affected, nor the likelihood that *you* might be affected. No doubt the apparent short duration of the 'average' power outage is what led OFCOM to allow telecomms providers to avoid having to provide back-up power supplies.

Fortunately, other people are better informed. On 14 November last, David Mitchell opined in *The Guardian* that BT's Digital Voice kills access to 999 in a power cut and 'That's not what I call progress'.

Lives will inevitably be lost

So, will every VoIP phone subscriber get a free battery back-up box? I cannot speak for every service provider but apparently BT users will not. The company did at least list home battery packs for subscribers they had transferred to Digital Voice, but they were chargeable and cost around £90. But look for the 'Cyberpower Back-up for Digital Voice' on the BT website now and you will read: 'We're really sorry but we've sold out of this product and are unable to obtain more stock.' Unbelievable – there is no other word.

The current ill-considered policy will undoubtedly cost lives. Few people will realise that their digital landlines will go down in a power cut, even fewer than those know that their fully charged mobile may not work either. Pressure must now be put on OFCOM to mandate that all landline phone subscribers should receive a free battery back-up unit that plugs into and supports all their existing main and extension telephones, with a standby time of at least 48 hours.

Users should also be warned that mobiles and cordless phones cannot be relied upon to work in a power cut, explaining precisely why their mobile may not work because their local base station may be knocked out by the same power failure and there's not much that landline and broadband users can do about that. Complain to your MP!

Win a Microchip RN2903 LoRa technology Mote

Practical Electronics is offering its readers the chance to win a Microchip RN2903 LoRa technology Mote (DM164139) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

The RN2903 LoRa Mote is a LoRaWAN Class A end-device based on the RN2903 LoRa modem. The RN2903 is a fully certified 915MHz module based on wireless LoRa technology. The RN2903 uses a unique spread-spectrum modulation within the sub-GHz band to enable long-range, low-power, and high-network capacity. As a standalone battery-powered node, the Mote provides a convenient platform to quickly demonstrate the long-range capabilities of the modem, as well as to verify interoperability when connecting to LoRaWAN v1.0 compliant gateways and infrastructure.

Worth $82.99 (approx £62.50) each

The Mote includes light and temperature sensors to generate data, which are transmitted either on a fixed schedule or initiated by a button-press. An LCD display provides feedback on connection status, sensor values and downlink data or acknowledgements. A standard USB interface is provided for connection to a host computer, providing a bridge to the UART interface of the RN2903 modem. As with all the Microchip RN family of products, this enables rapid setup and control of the on-board LoRaWAN protocol stack using the high-level ASCII command set.

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Net Work

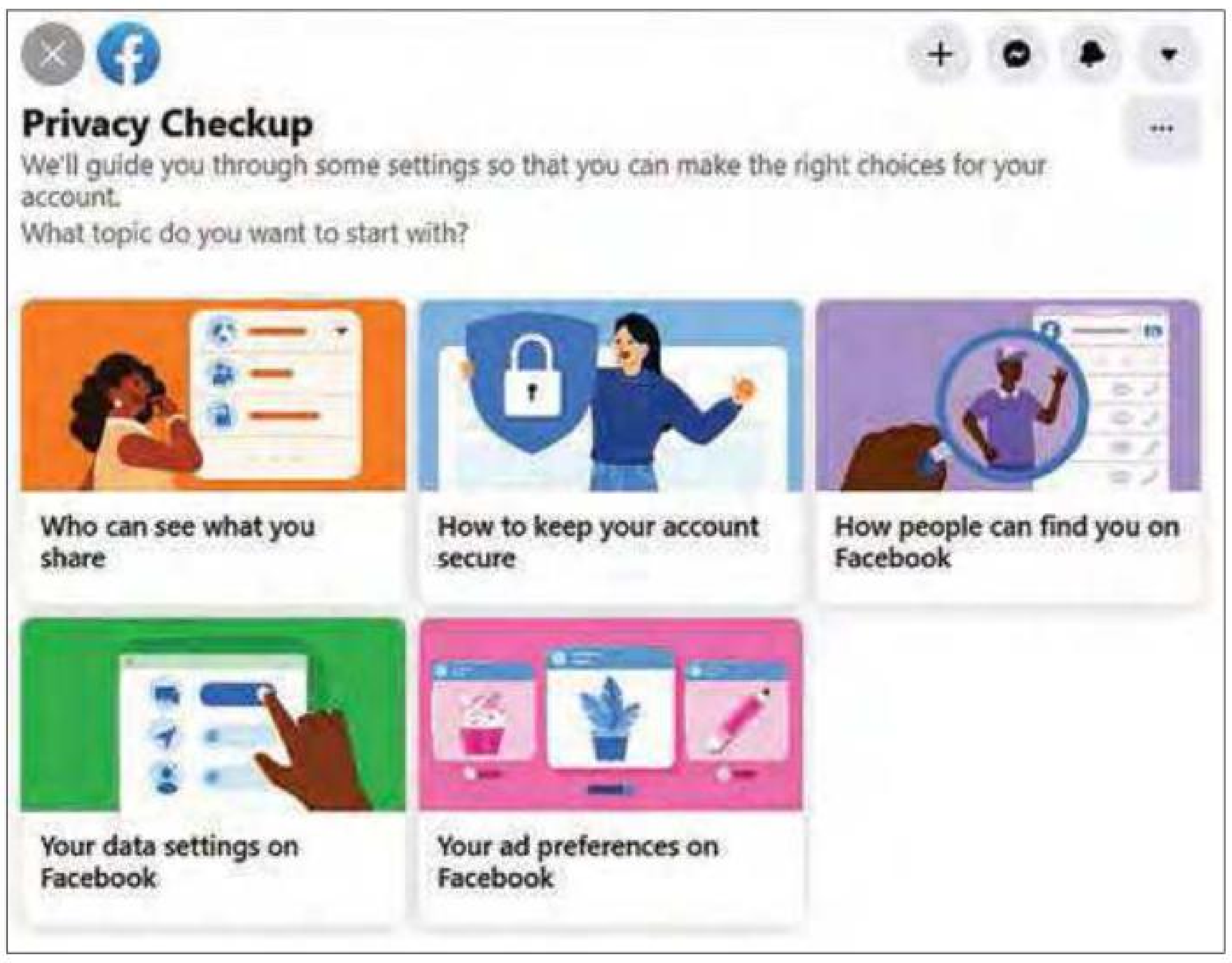
Alan Winstanley

This month's *Net Work* brings readers a round-up of trends emerging in the Internet and further afield in the fast-changing world of technology..

Way back in Net Work October 2018, I described how in 2004 a CNBC news anchor interviewed an earnest young fellow called Mark Zuckerberg. He'd started a small social media site for US universities called 'The Facebook,' which he thought might attract a few hundred users but, by then, the head count had jumped to 100,000. The site was originally dedicated to students eager to share their profiles and contact details, which allowed visitors to find 'interesting information about people,' as he put it. The cringe-inducing CNBC interview is still online at: **https://youtu.be/cUNX3azkZyk**

One in three

Facebook now has some 2.6bn users around the world, according to Statista. It's most popular in India (349m) followed by the US (194m) – as of the start of 2021. Viet Nam has nearly twice as many users (74m) as the UK. While Facebook has plenty of detractors, often centred on matters of privacy or monetisation, there is no doubt that the social media giant has become an integral part of many an Internet user's online experience. Facebook is here to stay, and provided you tread carefully, it's not all bad: there are plenty of topical Facebook groups covering, say, fascinating local history and countless hobbies or specialties such as restoring vintage radios, collecting old bottles or seashells (or even old mains plugs!), or making contact with long-lost friends or colleagues through arcane groups like the (chosen at random) *RHP Bearings (Ferrybridge) Appreciation Society*. As the new year gets under way and some of us reflect on years gone by, searching for old mates or workplaces on Facebook can become an immersive and evocative experience, often turning up photographs of old acquaintances, offices, factories, old company trucks, military aircraft, commercial vehicles or pictures of distant locations. Suddenly, a Facebook feed comes alive with group members reminiscing about friendships or swapping photos, scanned from decades-old collections of slides and prints stored in old biscuit tins for moments like now.



Privacy Checkup

We'll guide you through some settings so that you can make the right choices for your account.

What topic do you want to start with?

Who can see what you share

How to keep your account secure

How people can find you on Facebook

Your data settings on Facebook

Your ad preferences on Facebook

It's worth running a 'privacy check-up' in Facebook to confirm your preferences. Access it via your account.

A young Mark Zuckerberg explains the idea behind his new media site, 'The Facebook' (Image: YouTube / CNBC 2004)

Much has been written about the pros and cons of Facebook and there are plenty more resources online – when there's a problem it's often quickest to Google for the answer. There will undoubtedly be a community Facebook group covering your locality or interests – simply search for some keywords or names on the Facebook homepage. In fact, thanks to the use of geoIP, which tries to triangulate your physical location (give or take a little), soon advertisements and news from local media or suppliers will pop up in your Facebook feed. Many small businesses don't even have a website and rely on having a Facebook presence instead.

Facing up to Facebook

Facebook has tried to make it easier for users to understand all the privacy implications. Before joining a Facebook group, determine whether it's a public or a private one and whether it's hidden from public view – look at the group's 'About' summary. In public groups it may pay to be more measured with one's postings, especially if they risk coming back to haunt you years later. There are often some local 'selling groups' for trading goods, furniture and so on too, noting some groups are 'public' rather than being for members only. These groups often avoid the drudgery of selling on eBay, and are arguably a safer bet than buying or selling more widely on the dedicated Facebook Marketplace. (One in six Brits surveyed by ThinkMoney had been scammed in Facebook Marketplace, says ThinkMoney at: **https://bit.ly/pe-mar22-tm**)

As regular users know, Facebook uses an awful lot of powerful analytics and artificial intelligence when displaying contents or showering us with adverts. It's also a bit clever at suggesting other groups that might be of interest: the creepy feeling of being 'monitored' this way doesn't seem to bother regular users though. Facebook says it employs both AI and human moderators to screen out nefarious material as best it can – let's not get into politics or elections – but it pays to be discerning and vigilant. (Always ask yourself if suggestions are really in your interest, or just to promote the sender.) It's also worth checking your privacy settings; in your Profile, click the down-arrow 'Account' button (menu ribbon, top right) to access them, and run a 'Privacy check-up' to confirm your current status. A useful 'View As' button lets you see your own Profile as the rest of the world (ie, those who are not your 'Friends') would see it.

All of this takes enormous networking and data processing power, and for any readers who might be interested, I wrote about the construction of Facebook's first European data centre in Luleå, Sweden in *Net Work*, May 2016. It explained how an 'ideal' data centre would have an effective 'Power Usage Effectiveness' (PUE) of 1.0 (see: **https://bit.ly/pe-mar22-pue**). Facebook has 3.4 million square metres of data centres around the world and is very proud of their 'green' credentials. A third data centre was due to come online in Sweden during 2021, and Facebook states that its global operations have now achieved 'net zero' using 100% renewable power, which is no mean feat. You can read more about Facebook's data centres at: **https://datacenters.fb.com**

Living in the metavirtual world

As many readers will know, Facebook underwent a major change of identity during the latter part of 2021 when it rebranded itself as 'Meta'. Facebook is now a 'Meta company', Facebook's Portal LCD screens are now co-branded as 'Meta's Portal family', Meta built its first European data centre in Luleå, and so on. The group has been busily erasing its old name from swathes of its websites and swapping out logos.

In his video keynotes published late last year, Mark Zuckerberg, now 37, has some clear visions of where he thinks the connected world is heading next. He expects we will be hanging out in a virtual space dubbed the 'embodied Internet'. We're told that 'Meta's focus will be to bring the 'metaverse' to life and help people connect, find communities and grow businesses.' It seems we're nearly done with communicating using tiny screens on mobiles or staring at little faces on flat-panel Zoom or Team meetings all day long. He foresees the 'metaverse' as a virtual 3D world, one where its participants will live out new experiences in a virtually created space.

The future 'metaverse' will embrace VR to connect everyone together. There is even the suggestion that users will be able to 'teleport as holograms'. Images of Cortana, the holographic character in the XBox Halo video games, spring to mind (**https://bit.ly/pe-mar22-halo**). Microsoft adopted Cortana's name for its own virtual helper, to rival Google Assistant and Apple's Siri. The 'metaverse' will also appeal to educationalists, social networkers, gamers or families chatting via video feeds, and no doubt some sectors of business and commerce will embrace the metaverse concept wholeheartedly in years to come. There are even trends emerging of 'buying virtual space' in a metaverse: for example, the website **https://decentraland.org** is a virtual world owned by its users, where you can buy and sell pretty much any virtual property including 'land'. It's predicted that business and commerce will be queuing up to set up shop in these virtual worlds. As a sign of where things are heading, take a look and have fun building your own guest avatar at Decentraland.

Meta is investing billions of dollars creating a metaverse and of course it already has history in the form of the Oculus virtual visor, marketed by Meta Quest (**www.oculus.com**). The Oculus Research labs explore VR, AR and AI, and are tasked with looking ahead five to ten years. Both Sony and Apple are developing latest-generation VR headsets too. Some of the ideas are plainly fanciful at this stage, and although some of the basic technologies already exist, the metaverse itself is still some way off, Zuckerberg admits. As if Covid lockdowns, working from home and webcam exchanges aren't enough, the metaverse will leave us with even fewer reasons to interact physically with one other, go to school or college or even turn up for work at the office. You can learn more about Meta's visions, if you can spare an hour, by watching the Welcome PR video at: **https://bit.ly/pe-mar22-fb**

Microsoft is also entering the metaverse fray. The purveyor of Windows, Teams and Office software is bringing holograms to Teams virtual conferencing, where users can express themselves by building their own avatar. Watch out this year for Microsoft Mesh, which utilises Hololens VR headsets to enable users anywhere in the world to collaborate.

Mark Zuckerberg – actually, his avatar – meets and greets others in a metaverse get-together.

Sony's mobility aid

The move towards adopting electric vehicles grinds on, as does the rumour mill: the industry's worst-kept secret is that Apple, the world's first $3tn company, is working towards building its first EV ('Project Titan'), but nowhere will any official confirmation be found. That is sometimes a sign that Apple is indeed up to something and intends to surprise us all. Trials and test reports of self-driving cars, based on a Lexus SUV, have been attributed to Apple in recent years.

Will the EV bubble ever burst? Worldwide, electric car and truck projects are now too numerous to mention, although in January 2022's Consumer Electronics Show (CES) in Las Vegas, one consumer 'gadget' on show was an electric vehicle prototype from none other than Sony. The Vision S-02 concept car is Sony's second iteration of an electric vehicle, this time having an SUV form factor. Sony's first car, the Vision S-01 saloon revealed in 2020 is undergoing tests in Europe; car enthusiasts see this as a precursor to production, but the car appears to be Sony's testbed for utilising mobile 5G to upload vehicle telemetry to the cloud. Since April last year, Sony has been working with Vodafone Germany to test 5G communications with their car, and Sony's EV reportedly managed to drive by itself, switching seamlessly between 5G antennae. Using its smartphone experience, Sony also aims to use 5G to update the car's software and interact with other 5G services.

Sony is, however, establishing a new division – Sony Mobility – to explore the viability of small-scale EV production, perhaps with Tesla's market in mind, and a YouTube video showcases the first Sony car at: **https://youtu.be/P0cQQvvM5Qk**. Meantime, the company says

(Left) Sony's Vision S-02 concept EV (left) is a testbed for sensors, 5G and telemetry; it may see limited production in the future. Pictured with the earlier S-01 saloon. (Right) Sony has been testing 5G mobile systems with Vodafone in Germany since last year.

Russia's 21,000 tonne *Akademik Lomonosov* is a floating nuclear power plant supplying electricity to the Arctic city of Pevek. (Image: Rosatom)

it is 'currently conducting functional verification tests in Europe toward the release of Level 2+ advanced driver assistance systems (ADAS) on public roads.' Modern cars, whether electric or fossil-fuelled, increasingly have driver aids such as GPS, road sign recognition, collision avoidance or radar blind spot assistance, so maybe the next generation of aids is waiting in the wings. In Europe (and likely heading our way), new cars are mandated from mid-2022 to be fitted with Intelligent Speed Assistance (ISA), a GPS and traffic-sign speed limiting feature intended to force cars to slow down, as discussed in previous *Net Work* columns.

Next, electric trucks

There is of course relentless pressure on battery design and production as the car and truck market gradually migrates from petrol and diesel in the coming decades. Electric semi-articulated lorries (or 'semis' in the US) are in the pipeline, although Tesla has postponed its plans for a semi until sometime later this year, citing battery and component shortages. At CES 2022, American truck maker Kenworth exhibited their new electric semi (see: **https://bit.ly/pe-mar22-ken**) which has an estimated range of [up to] 150 miles: a diesel lorry fitted with dual tanks can have a range of easily ten times that figure. Another design problem the freight industry faces is the need to lug a constant dead weight of rechargeable batteries around, which could make a lorry's operating costs unviable. Although planes and (petrol/diesel) road vehicles gradually get lighter as they consume fuel, electric vehicles carry the same dead weight all the time. (Incidentally, similar trade-offs affect our electricity supply lines: it's cheaper to string catenaries of air-cooled aluminium wires between pylons, but sometimes there's no choice but to bury thick cables underground, which is costlier. Utility companies try to optimise the mix to minimise costs, but recent power outages due to bad weather are likely to see costly cables buried underground anyway.)

The search continues to raise rechargeable battery density and reduce the weight and volume, as well as eliminating the end-user's real worries ('anxiety') about range and charger availability.

Another factor is the time needed for recharging an EV. Israeli manufacturer StoreDot claims to have achieved a major milestone of producing silicon-dominant Extreme Fast Charge (XFC) battery cells that charge in ten minutes and maintain at least 80% of energy storage capacity after 850 consecutive cycles. The firm aims in early 2022 to accomplish 1,000 consecutive XFC cycles, StoreDot says, and their new chemistry has produced a Li-ion battery that can be fully charged in just five minutes. More details are at: **www.store-dot.com**

Is there enough capacity?

The problem of generating enough electricity to power a new breed of electric vehicles, when there is barely enough capacity in the network or a sufficient number of EV charging points, has been well aired in *Net Work* and in the short-to-medium term these problems show no sign of abating. The issues affecting Russian gas supplies in an increasingly volatile Eastern Europe have yet to be played out, and it seems certain that small modular (nuclear) reactors (SMRs) will play a key role in providing electricity in the future. The jury is out, in mainland Europe anyway, as to whether SMRs can rightly be classed as 'green' energy.

NuScale sets its sights on Europe

Last month, I mentioned that the US multinational NuScale had ambitions to deliver its own 'VOYGR' scalable 77MW SMRs into Eastern Europe. In Ukraine last September, the US Trade and Development Agency deftly granted funds to Ukraine's Science and Technology Centre to see whether NuScale's SMRs would be a good 'fit' in that country, and if regulations got in the way, how they could be 'changed', says NuScale. Last December, NuScale signed another Memorandum of Understanding with Kazakhstan Nuclear Power Plants in central Asia to adopt VOYGR reactors. NuScale has been buoyed by the early interest and is planning to go public and form NuScale Power Corporation, with 60% of operations still controlled by the engineers and project managers of the Fluor construction company.

Although NuScale's design received approval in the US last July, its aim to deliver its first working SMR is at least half a decade away, in 2027. The UK's Rolls-Royce SMR is not far behind the curve, with plans for its own SMR having been submitted for approval to the regulatory authorities. China also has great ambitions to dominate the global SMR market in years to come, and a fully operational SMR recently went on stream in China and is said to be generating electricity into the locality. According to the IAEA website, the Shidao Bay-1 200MW reactor has been ten years in the making and made its first grid connection on 20 December – more details at: **https://bit.ly/pe-mar22-shi**

China, along with other countries, is also exploring the viability of nuclear reactors that use thorium (instead of uranium) dissolved in liquid fluoride salts which can also act as a coolant, instead of using water. The idea originated in the US in the 1940s, but American trials in the 1960s revealed potential problems with corrosion and poor efficiency, according to Live Science. China's water-free, molten-salt reactor would be a world first in a country where supplies of thorium are plentiful, and the fact that no cooling water is needed would make the plant ideal for siting in the Gobi Desert, for example. It is understood that China completed a small 2MW pilot project last year, but it will be another eight years or so before a commercial version is ready: China then expects to export the reactor globally.

Floating power plant

I sometimes wonder why, following a natural disaster such as a hurricane or tsunami, a nuclear-powered ship or submarine couldn't simply rock up offshore and supply its own power to the stricken shoreline. No doubt there's more to it than hooking up the vessel's batteries using some hefty jump leads, though...

In 2019, Russia launched the world's first purpose-built floating nuclear power plant (FNPP). The 21,000-tonne vessel *Akademik Lomonosov* uses two 35MW reactors and is the first in an expected series of low-power transportable power plants. Russia has applied its experience of building nuclear-powered icebreakers to produce a floating power station that can power remote regions, places where the overland delivery of electricity or the use of renewable energy (wind, solar) would be impossible.

After setting sail from Murmansk, the *Akademik Lomonosov* is now serving Pevek, Russia's northernmost city where it is permanently moored to a dedicated pier after replacing an old coal-fired power station. The vessel's nuclear power plant has a lifespan of about 40 years, and special dams were built to safeguard against icebergs or collisions with the shoreline. Russia's *Rosatom* agency adds that the ruggedised vessel operates in inherently safer maritime conditions than any nuclear-powered icebreaker would. The fascinating story of the *Akademik Lomonosov* can be found online at: **www.fnpp.info**

A hybrid tools heads-up

Last month, I showcased one or two tools from the Ryobi 18V OnePlus range of tools, including a soldering iron, that share a common 18V Ni-MH battery. The American market is much larger than the European one for Ryobi and an interested user mentioned Ryobi's 'hybrid' soldering station, the Ryobi P3100 that appears on some websites. Then one or two other 'hybrid' tools came to light, including a work light and a portable fan. The idea is that these hybrid tools work on either 18V batteries or the mains, which would be an ideal solution for, say, a multi-purpose soldering station that could be used on the bench or in the field. But before you take the plunge, readers, beware: these tools are for 110V mains only and even though they appear on European and UK websites (including Amazon UK) at silly prices, there is no sign of any 230V version. In fact, the mains voltage rating isn't mentioned anywhere, not even on any product web page. Whether Ryobi would introduce a 230V hybrid for Europe is therefore doubtful, as they seem to take it for granted that customers use the 110V mains.

I noticed another twist on the Ryobi OnePlus range, namely using an 18V battery to charge a smaller 'slave' power tool. The Ryobi Mini hot melt glue gun RGLM18-0 (or P306) has a base station that cradles on an 18V battery and takes about four minutes to heat up, making it quite slow to get going. The glue gun uses 7mm hot-melt sticks and its compact design is intended for hobbyists and crafters. Only by searching YouTube did I find how it really works – the tool has no battery but builds up sufficient heat to melt a whole glue stick (see: **https://youtu.be/X0Nd-va_lwg**) in between charging.

Ryobi's 'hybrid' 18V OnePlus tools such as this P3100 soldering station can also run from the mains. Beware, though, they are 110V AC only.

Meanwhile Dremel, the hobby power tool company owned by Bosch, recently introduced what it says is the world's first 'smart' brushless rotary tool, the model 8260. It has a 12V Li-ion battery and Dremel claims a 20% power improvement over its most powerful mains-corded tool (the 4300). It can connect by Bluetooth to the Dremel app to easily control, monitor and manage the rotary tool, receiving 'tool management and performance alerts' on a smartphone or tablet along with accessory and material guidance, which anyone who has grappled with Dremel's accessory codes might appreciate. A YouTube promo video at: **https://youtu.be/HbO-nVvvYeA** drove me to distraction, unfortunately. It lists at US$169.99 but has yet to arrive in the UK or EU.

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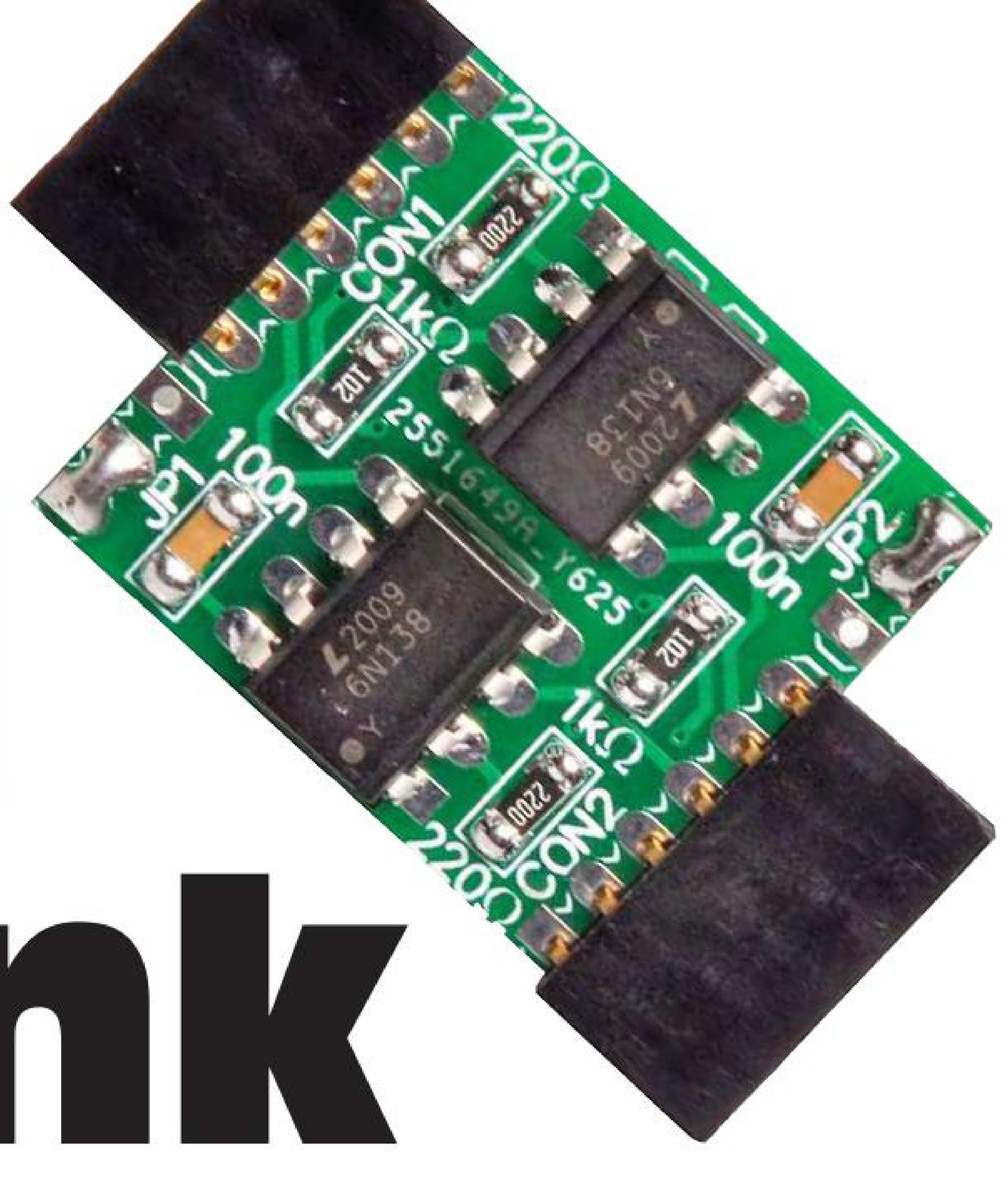
Mini Isolated Serial Link



This tiny module (about the size of a postage stamp) provides bidirectional, isolated, full-duplex serial communication. That makes it ideal for when two (or more) boards running from separate supplies need to pass information to each other. It can also carry isolated logic signals.

Next month, we feature a *High-current Four Battery Balancer* project that can handle more than four batteries (or cells) by stacking multiple units. But for that to work, they need to communicate with each other, even though their ground potentials will be quite different; possibly as much as 60V DC apart.

To connect their onboard serial links so they can work as a single unit, a serial isolator is needed. This little device uses optoisolators to provide thousands of volts of effective isolation while allowing the serial data to pass through unchanged.

We will reference the *Battery Balancer* throughout this artice, but it is of course useful in many diverse applications. Another important use for a device like this is connecting a computer to a device that you're testing, to prevent any possibility of damage should the device malfunction and feed a high voltage to its serial pins.

If you have a single battery balancer and wish to monitor or control its operation on a computer, it would be a good idea to use this isolator between the two, for safety.

We already published the *Zero Risk Serial Link* in January 2020 for this purpose, but that board includes a power supply for the isolated device, which often isn't necessary.

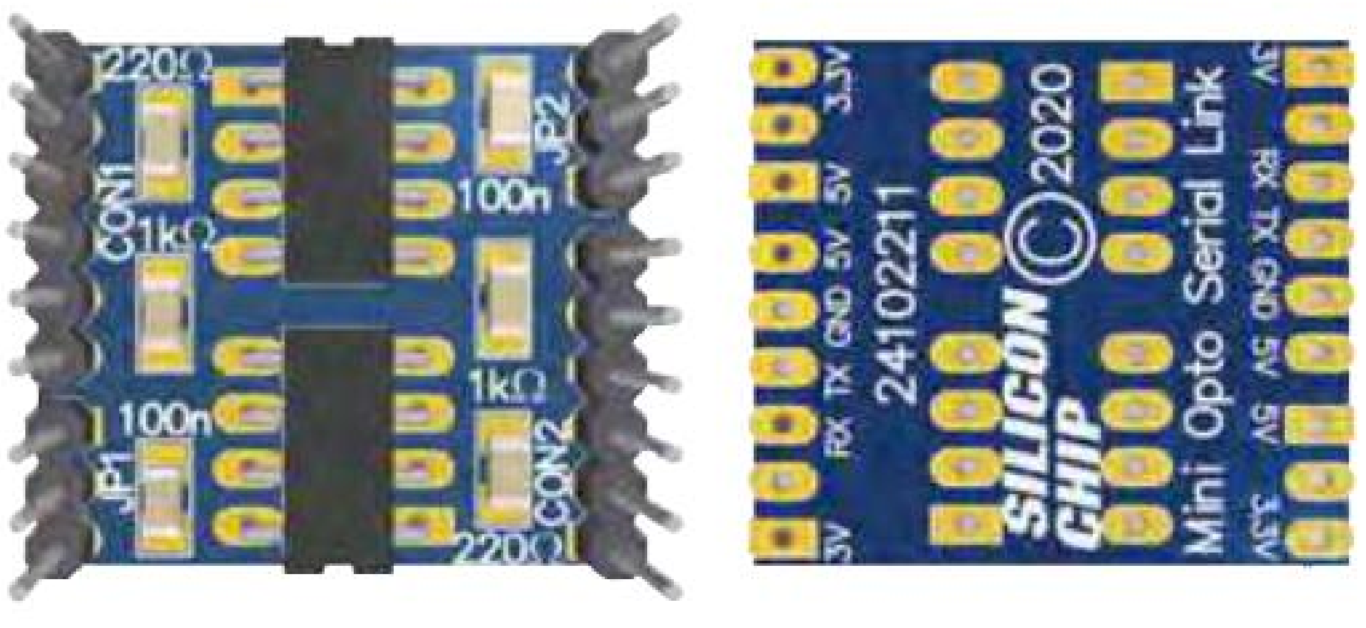
That makes the board much larger and more complicated than necessary. In cases where both of the communicating devices have individual power supplies, this design is a better choice.

New design

By dispensing with the power circuitry and using six passive SMDs, we've managed to squeeze the required circuitry into a PCB that measures just 26.5 x 23.5mm.

That's small enough to be connected inline with your serial link and encased in a short length of large diameter heatshrink tubing. Despite this small size, it isn't hard to build.

By Tim Blythman



These same-size renders of the front (left) and rear (right) of the Mini Isolated Serial Link PCB show just how tiny it is. Whether you use vertical header pins, as shown here, or horizontal, as shown in our photos, is up to you. (Incidentally, the renders shown above were taken directly from the new Altium Designer 21.)

Fig.1 is the complete circuit diagram. The operation is simple. On the transmitting side, a current loop is formed between the TX pin and the selected supply rail (3.3V or 5V) via one optoisolator LED (OPTO2 for CON1 and OPTO1 for CON2). This is via a 220Ω current-limiting series resistor.

So when the TX pin is high, no current flows through the LED, and when it is low, about 10mA (for a 3.3V supply) or 18mA flows. This pulls the RX pin at the opposite end low by activating the Darlington transistor in the other half of the optoisolator.

When no current is flowing through the LED, the Darlington is off, so that pin is held high by a 1kΩ pull-up resistor.

The configuration is identical for data flowing from CON2's TX pin to CON1's RX pin as it is in the other direction. A 100nF bypass capacitor stabilises the voltage across the Darlington on either side.

Pin headers CON1 and CON2 are identical, and could be soldered directly to one of the communicating boards (eg, a battery balancer) using four of the six pins.

Alternatively, all six pins of CON1 can be soldered to a CP2102-based USB-serial module, thereby allowing the combination to plug straight into a computer.

Note that only four pins are connected in either case. For the CP2102 module, the 3.3V, RX, TX and GND pins are used.

JP1 gives us the flexibility to choose which pin is used for power. If JP1 is set to the 5V position, power is taken from the pin next to GND on CON1. For a CP2102 module, this is the 5V USB supply. (However, it corresponds to the 3.3V supply pin on the *Battery Balancer* – the *Battery Balancer's* serial port operates at 3.3V, so that is where we want to connect to.)

For CP2102 modules, you would generally place the jumper in the 3.3V position, which connects to the supply pin marked 3.3V on those modules.

Indeed, regardless of whether the GND on either side is at the same potential, the *Mini Isolated Serial Link* can also be used to provide translation between different signalling levels.

To keep the PCB small, we have not added a slot in the PCB to increase the creepage distances, as this would require a larger PCB area to prevent the PCB from breaking when flexed. **Thus, the *Mini Isolated Serial Link* is *not* suitable for mains voltage isolation.**

Communication details

Practically all TTL serial communications we have seen have the signals idling at a high level.

Because we have arranged the optos to only switch on when the input voltage is low, and because the Darlington outputs pull low when active, the signal is not inverted across the device.

If we had terminated the TX current loops to GND instead of the supply rail, it would instead act as an inverter.

The sharp-eyed among you might have noticed that we're using a different optoisolator in this project compared to the *Zero Risk Serial Link*. This option is slightly more space-efficient for similar speeds.

Features and specifications

- Provides optically isolated bidirectional serial communications
- Baud rates up to 57,600 (using 6N138) or 1,000,000 (using 6N137)
- Each device can have 3.3V or 5V signal levels (ie, it can act as a level shifter)
- Supply current (3.3V): between 0mA (TX and RX high) and 13mA (TX and RX low), average ~6mA
- Supply current (5V): between 0mA (TX and RX high) and 23mA (TX and RX low), average ~10mA
- Offset voltage: up to 100V DC or 60V AC between GND on either side.

Dual versions of the PC817 devices used for the Zero Risk Serial Link exist, but they are now obsolete, so we had to find an alternative.

The footprint used by the 6N138 is also very similar to that used by the 6N137 optoisolator that we have used previously. The 6N137 is a very fast device (up to 10Mbaud), but requires a 5V supply to meet specifications.

In other words, if both sides of your *Mini Isolated Serial Link* will operate at 5V, you could replace OPTO1 and OPTO2 with 6N137s and work at a much higher speed, up to 1Mbaud or possibly even more.

But because we wanted this design to have the flexibility to work with devices using 3.3V signalling levels, as it is very common (and a requirement for use with the *Battery Balancer*), we are using 6N138 parts instead.

The 220Ω resistor value is chosen to work with both the 6N137 (at 5V) and the 6N138 between 3.3V and 5V.

The 6N138 has much lower current requirements than the 6N137, so you could increase those values up to around 1kΩ if your transmitter has limited current capacity, or you want to reduce the supply current somewhat.

Similarly, the 1kΩ pull-up resistors could be increased in value if the current consumption on the output side is a problem. However, this will limit the maximum baud rate because the circuit depends on this resistor to pull the output high promptly.

Our testing shows that this device will work reliably up to 9600 baud with 3.3kΩ LED series resistors (instead of 220Ω) and 10kΩ pull-up resistors replacing the 1kΩ types.

The 3.3kΩ value is the largest possible due to the nominal 0.5mA threshold current needed by the opto LEDs for correct operation; the 10kΩ value could go higher, but at risk of worse interference rejection.

Maximum baud rate

The 6N138 datasheet indicates rise and fall propagation delays of around 10μs and 1.6μs under typical conditions, setting a hard limit of about 100,000 baud as the bits will start to run into each other.

A graph also indicates that the rise delay increases with temperature, which will further skew and distort the data.

We did some tests with a CP2102 module plugged into each side of the *Mini Isolated Serial Link* to see what sort of speeds we could achieve with the specified components. This testing occurred at room temperature, so

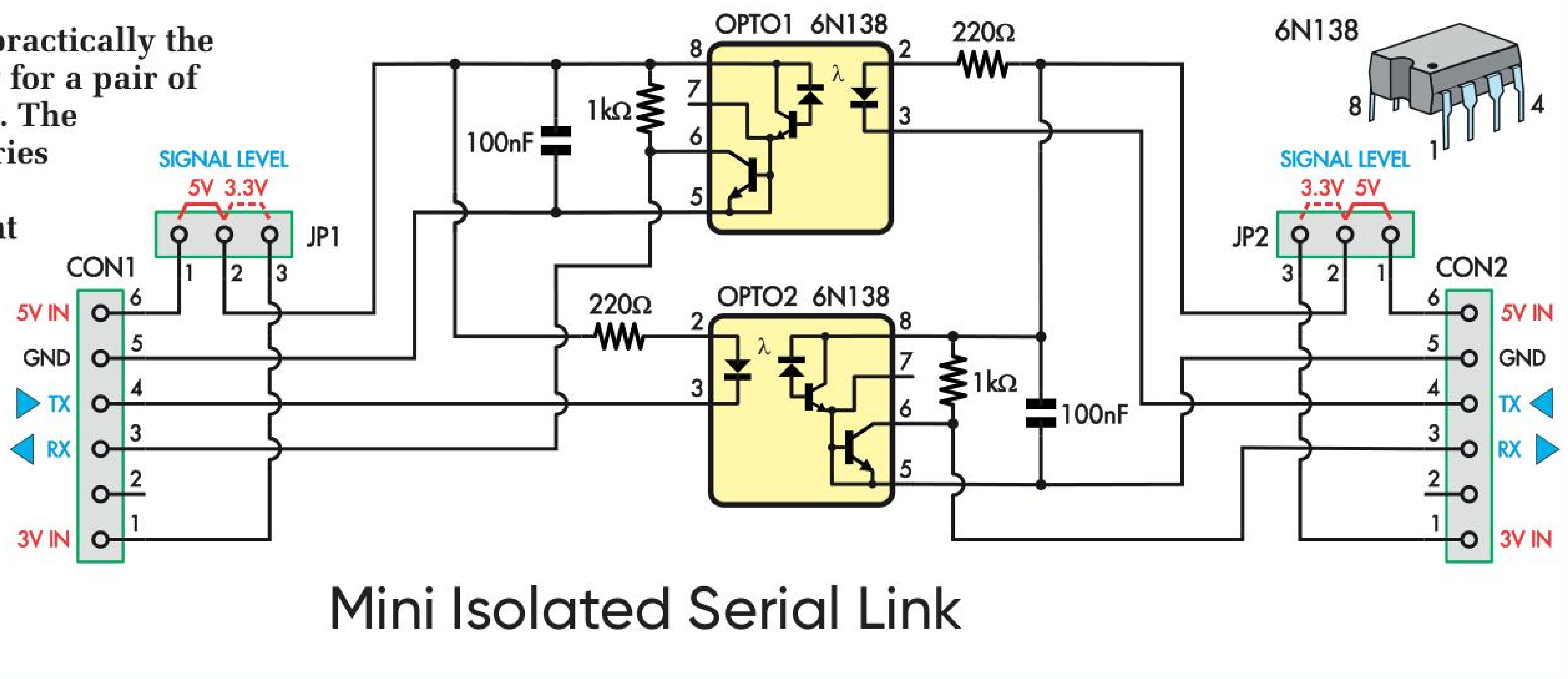
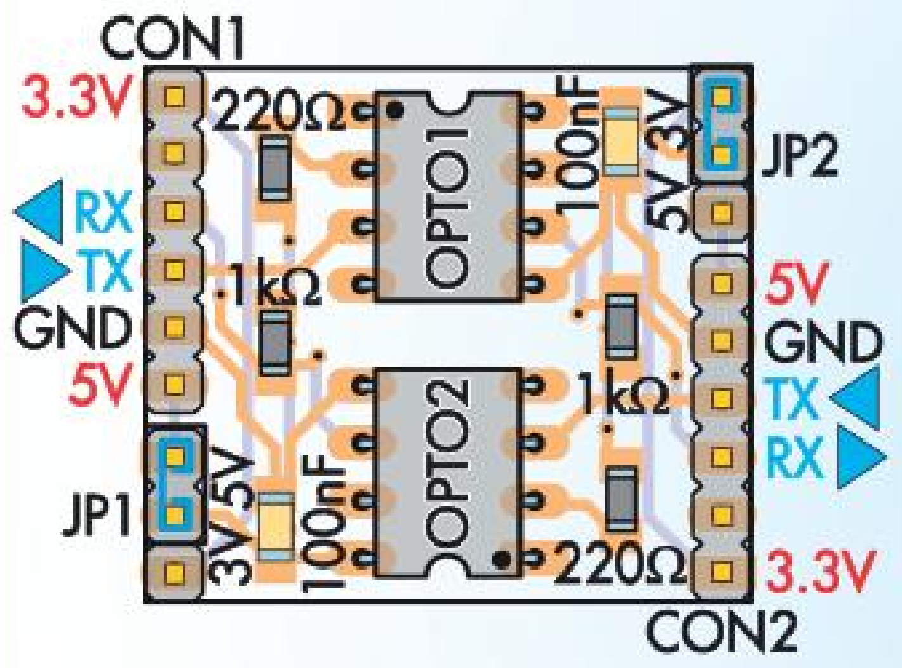


Fig.1: the circuit is practically the minimum necessary for a pair of 6N138 optoisolators. The 220Ω resistors in series with the opto LEDs limit the LED current while the 1kΩ pull-up resistor holds the output high when the opto is off. The 100nF bypass capacitors are the minimum specified in the 6N138 data sheet.



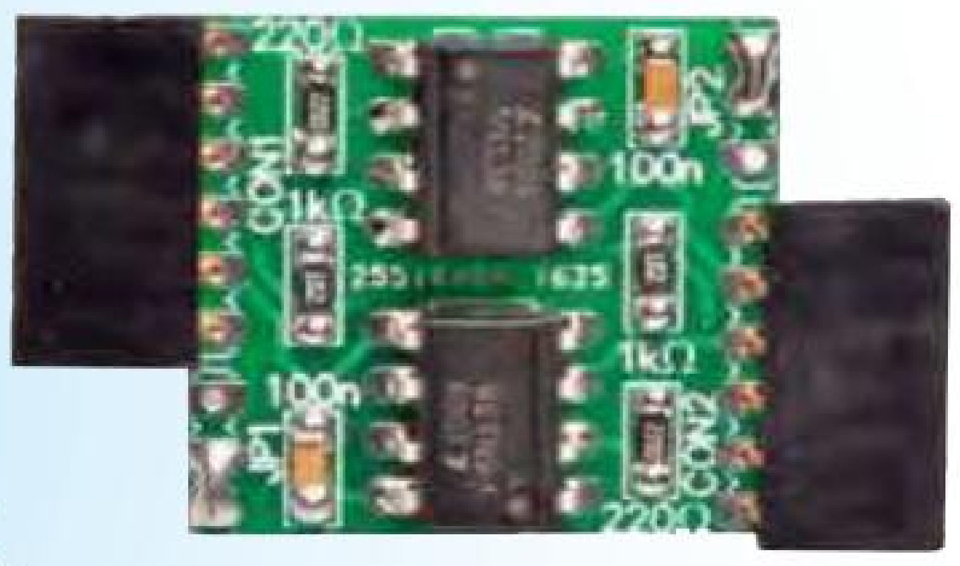


Fig.2: as suggested by the circuit diagram's symmetry, the component layout and PCB traces are also symmetrical if rotated 180° about the centre. Ensure that each opto's pin 1 faces towards the edge of the PCB. To keep the PCB small, we have put the pin markings on its back. Both the overlay and photo are full size.

we would expect the results might be worse at higher temperatures.

Testing at 115,200 baud led to data being corrupted about once every 20 bytes. This is not surprising given that propagation delays noted above.

At 57,600 baud we didn't see any errors at all, nor at 38,400 baud.

Non-serial data uses

Note that the *Mini Isolated Serial Link* can also be used in situations where it does not carry serial data. It will work at any speed down to DC, and could simply be used to pass any low-speed logic signals between two systems, such as an error flag, reset signal or on/off signal.

Option

The few options for this project revolve around the connections to CON1 (and identical CON2) and the corresponding configuration of JP1 and JP2.

For connecting to a CP2102 module, use a 6-way header (pins or socket) to suit the module. In this case, the associated jumper is set in the 3.3V position.

While we have shown a pin header and jumper shunt, you could simply use a short wire link to bridge two pads if you are sure you won't change this configuration.

For our testing, we fitted the unit with a 6-way female header socket to allow a CP2102 module with a pin header attached to plug in, as that is how a CP2102 module typically comes.

But you could reverse that, or just solder the two together using a single pin header.

For connection to 4-way header on the *Battery Balancer*, it's a case of bridging the 5V pad on JP1 or JP2. This means that the four central pads on that side of the *Mini Isolated Serial Link* (in the order 5V, GND, TX, RX) are available for connection.

These four pins would also be the preferred way of using the *Mini Isolated Serial Link* with jumper wires or similar – if for no other reason than general neatness. You could use a 4-way socket header plugged into a 4-way pin header on the Battery Balancer or even solder it directly to the PCB.

We've built a few variants to show in the photos, so you can see how some of these options work. Since it is a small and simple project, you can make these selections once the other parts have been fitted.

Construction

The *Mini Isolated Serial Link* is built on a 27 x 24mm double-sided PCB, coded 24102211 and available from the *PE PCB Service*. Refer to the PCB overlay diagram, Fig.2, to see where the parts go.

Parts list – Isolated Serial Link

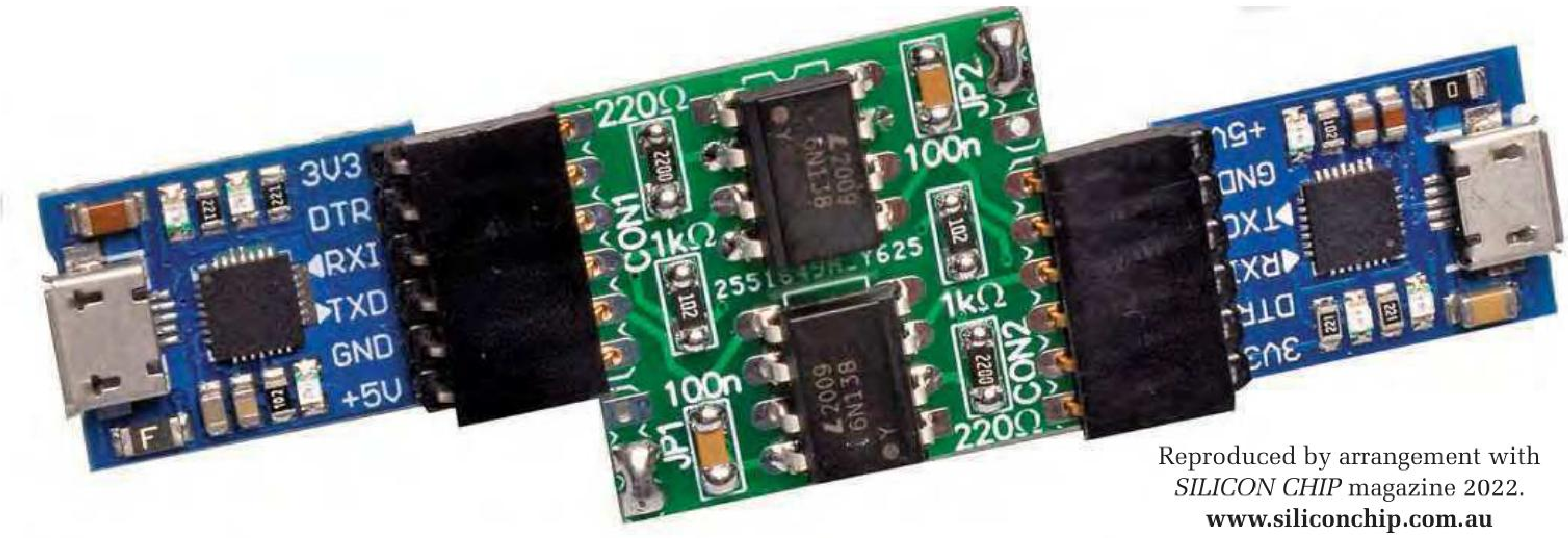
- 1 double-sided PCB coded 24102211, 26.5 x 23.5mm available from the PE PCB Service
- 2 6N138 optoisolators (DIP or gullwing SMD; see text for alternatives)
- 2 1kΩ SMD resistors, M3216/1206 imperial size (see text for alternatives)
- 2 220Ω SMD resistors, M3216/1206 imperial size (see text for alternatives)
- 2 100nF 50V X7R SMD ceramic capacitors, M3216/1206 imperial size
- 2 6-pin headers (CON1,CON2) (see text for other options)
- 2 3-pin headers with jumper shunts (JP1,JP2) (see text for other options)
- Jumper wires etc to suit your application

If you are using SMD (gullwing) optoisolators, fit these first; otherwise, leave the through-hole variants until last.

Like any project using surface-mounted parts, solder flux, tweezers, magnifiers and a fine-tipped iron are handy to have, while solder braid (wick) will help with solder bridges. But this project is simple enough that you might get away without them, as long as your eyesight is good!

To fit the SMD optoisolators, align the parts with their pads, noting that pin 1 of each part is at the edge of the PCB; the two parts are rotated 180° relative to each other.

Tack one lead to its pad and check that it is correct, especially that you can access the pads on both sides of the optoisolator and that all pins are flat against their pads. If not, melt the solder with the iron and tweak the part until it is aligned and symmetrical.



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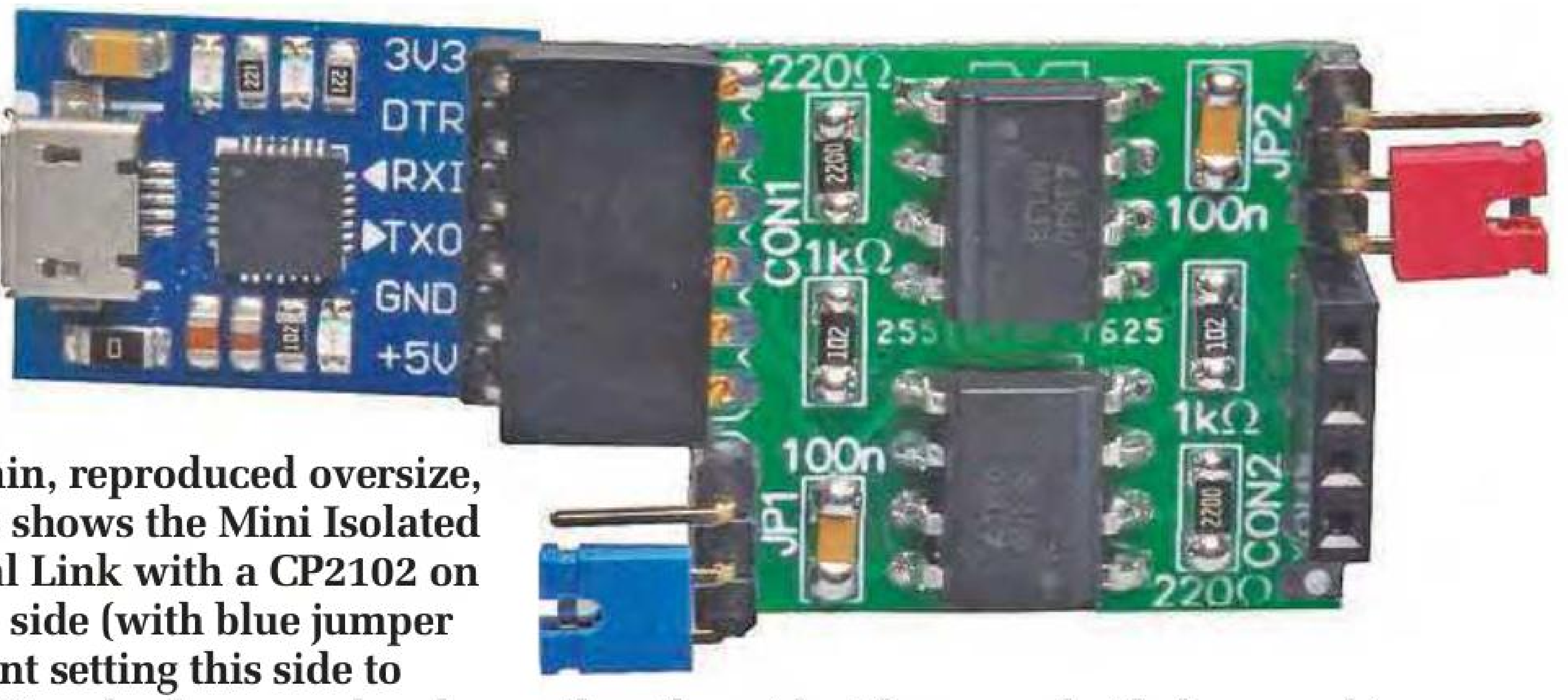
This oversize photo show how you could connect two computers over a serial link while providing opto-isolation. Two CP2102s are connected to the Mini Isolated Serial Link using female header strips at CON1 and CON2. The jumpers JP1 and JP2 are set to the 3.3V position using blobs of solder.



Again, reproduced oversize, this shows the Mini Isolated erial Link with a CP2102 on one side (with blue jumper shunt setting this side to 3.3V) and a four-way header on the other side. The second side has a red jumper shunt fitted to source power from the topmost pin on the four-way header.

Solder the remaining pins. You can flip the board over and apply more solder through the holes in the pads if you want to be sure they are connected properly.

Fit the resistors and capacitors similarly. Check each part against the photos and overlay.

Secure each part in the correct place with one pin before soldering the remaining pin. Our photos show large but shiny balls of solder. In this case, as long as there are no bridges, more solder is better than not enough.

If you are using through-hole optoisolators, fit them now. Gently bend the leads to allow them to slide into the holes.

You may be able to feed the leads into one side, then use the PCB to bend the leads so that the other side can be rotated into place, allowing the leads to spring back and hold the part in place (or use flat pliers or an IC lead straightening tool before insertion).

Check that the pin 1 markers are towards the edge of the PCB then solder one pin. Check that the parts are flat, then solder the remaining pins.

If you are using pin headers and jumpers, fit these next. If setting the supply options (JP1, JP2) permanently, use short lengths of tinned copper wire (or component lead off-cuts you might have from another build) and trim the excess after soldering them in place. Finally, fit the headers you need and/or solder the board to another device like a CP2102 module (or next month, the *Battery Balancer*) as needed.

Testing and usage

The *Mini Isolated Serial Link* is a simple enough design that it should 'just work' as long as you exercised care during construction. However, if you must test it first, use the arrangement shown with two CP2102 modules and open two serial terminal programs on your computer. We find that TeraTerm is a simple but versatile terminal program (and it's nice and free!).

There will be more information for use with the *Battery Balancer* next month on how to connect two Balancers using the *Mini Isolated Serial Link*. Essentially, once they are connected, they should automatically detect each other and begin communicating so that they act as a single five-to-eight-battery (or cell) balancing unit.

Our photos show various other ways of connecting the *Mini Isolated Serial Link*.

Because of the inherent symmetry, you can treat each side of the PCB independently to mix and match what you are connecting to it.

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When you really DON'T want to be interrupted . . .

I'm busy. Go away!

OK, it's a bit tongue-in-cheek . . . but it could have other, more serious uses. The *Busy Loo Warning* flashes a bright LED light on the door when you, ahem, don't want someone barging in. When you leave and open the door the light goes out! It's a simple idea with a real simple circuit – but it makes a superb beginner's project.

The idea for this little project came about when avid reader John Chappell was sitting, reading his latest copy... and the loo door burst open, with obvious embarrasement all around.

So maybe he had taken a bit longer than normal; maybe he was so engrossed in the magazine that he didn't hear anyone yelling out... but it started him thinking how to avoid the delicate situation in the future.

One problem was that the door lock, umm, didn't. So without replacing the lock, how to let others know that the best seat in the house was, umm, occupied – without the embarrasement!

Light bulb LED moment

Of course, that was the answer: a bright, flashing LED that would let others know not to barge in.

If it was made somewhat automatic – ie, it turned off when the outhouse door opened to let him out, so much the better. And this really simple circuit is the outcome.

When the pushbutton (S1) is pressed, both the LED mounted on the door and the internal LED start flashing.

Why two LEDs? One is the ultrabright warning LED mounted on (or through) the door to warn others that it is occupied. The second (internal) LED merely confirms that the circuit is operating.

Overkill? Perhaps – but at the cost of a 5p LED and a 2p resistor, it doesn't add much cost to the project.

When the loo door opens, a magnetic reed switch resets the circuit and the LEDs turn off. It really is that simple!

As we said earlier, it makes a great beginner's project. Parts are as cheap as chips; it's battery operated (and the battery will last for yonks) and it doesn't use any of those pesky surface-mount devices that beginners have so much difficulty soldering.

Total assembly time shouldn't be much more than an hour.

Original by John Chappell

The circuit

It's shown in Fig.1 – and as you can see, there's not much to it!

It's based on a 4093B CMOS quad 2-input Schmitt trigger NAND gate chip (IC1). Now if all those words scare you, don't worry: see the panel 'What is a NAND gate?' and all will be revealed.

The four NAND gates are configured in different ways. IC1a is an inverter: when its inputs are low, the output is high (and vice versa).

With the door closed, the magnet pulls the 'normally open' reed switch closed, which in turn means IC1a's inputs are both low – so the output is high.

IC1b and IC1d form a latch with the inputs to IC1d normally high. Think

SILICON CHIP
Push to warn!
Dunny Busy Warning!

You're looking at the entire project! On the left is a reed switch and magnet which turn the LED off when the door is opened. At right is the door-mounted ultrabright LED, while the internal LED in this case is integrated with the pushbutton 'start' switch

of a latch just like a door latch: it's normally at rest but needs someone to actuate it.

In this case, when the push button ('Start') switch is pressed, the latch is reset by forcing pin 12 of IC1d low which forces the output, pin 11, high.

This also enables IC1c, with its 47kΩ resistor and 10µF capacitor, to start oscillating, with its output going high and low at a rate set set by the time it takes the tantalum capacitor to charge and discharge – in this case the rate is about one second.

As it goes low, the two LEDs connected in series between its pin 10 output and +9V become forward biased and therefore light up.

You can change the flash rate by changing the resistor and/or capacitor. Increasing either (or both) will slow the rate down and, as you would expect, decreasing will speed the rate up.

When the door opens, the reed switch opens (when the magnet moves away), IC1a inputs go positive because of the 100kΩ resistor connected to 9V and the circuit reverts to its dormant state.

Power

The whole circuit is powered by a single 9V battery which, due to the intermittent drain, should last for almost as long as its shelf life. For the same reason, no on/off switch is provided or needed. (Of course, if you decide to read *War and Peace* during your 'visits' you might not get quite that life).

The battery snap leads can connect to a header set, or feed under the board and up through the hole at bottom left before soldering to their respective pads from the board top. This gives some strain relief to prevent the rather thin leads breaking off.

A 1N4004 silicon diode is included in series with the battery to prevent damage if you try to connect the battery back-to-front (surprisingly easy to do!)

A single 10µF capacitor bypasses (or filters) the 9V supply. While a tantalum capacitor is specified in the parts list, you will probably note from the photos that a standard 10µF 16V

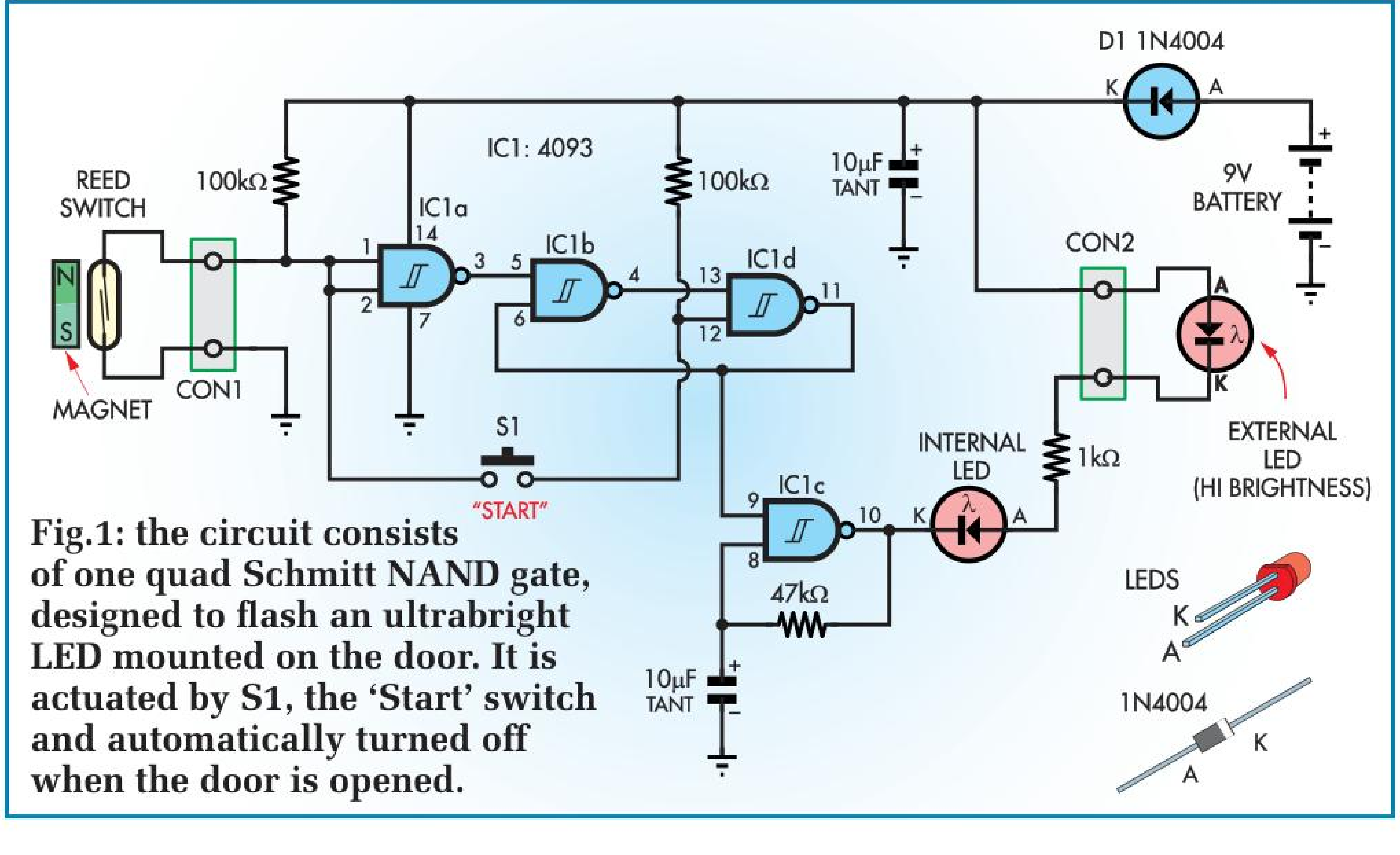


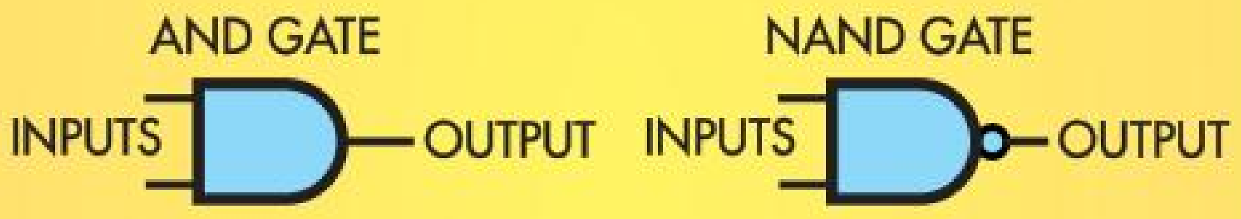
Fig.1: the circuit consists of one quad Schmitt NAND gate, designed to flash an ultrabright LED mounted on the door. It is actuated by S1, the 'Start' switch and automatically turned off when the door is opened.

What is a NAND gate?

Inside the 4093B chip there are four identical gates, each one operating completely independently of the others (but with a single power supply). That's why it's called a 'quad'.

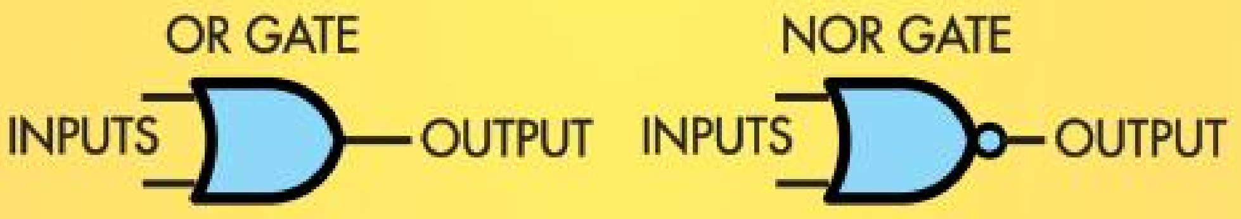
First, we'll look at an AND gate. Think of a gate as you would a gate in a fence. It can be either open or closed. With two gates, BOTH have to be in the same state, open or closed, to have any effect. With an AND gate, if both inputs are high, the output will be high. If either is low, the output will be low. That's why it's called an AND gate.

But the 4093 has extra circuitry in each gate which 'inverts' the output. So instead of both inputs going 'high' resulting in a 'high' at the output, both inputs going high result in a 'low' at the output (and vice versa). This makes it a NAND gate, an abbreviation for NOT AND. The little circle at the gate output tells you that it is a NAND gate (an AND gate won't have the circle).



Before we leave the AND/NAND gate, you'll often see another type of simple gate, the OR/NOR. With this gate, as its name implies, either input – one OR the other – can be high to bring the output high.

But if it's a NOR gate, as distinct from an OR gate, the output will be inverted (just like the difference between NAND and AND gates).



Finally, where does the 'Schmitt Trigger' part come from?

In most gates, the transition between the high and low states is fairly wide – it needs to be below a certain voltage to be low (close to 0V) and above a certain voltage to be high (much closer to the supply voltage). Voltages between the low and high states are not defined.

However, this is often undesirable, so circuitry is included inside the gate which makes the low to high or high to low transition much more defined due to 'hysteresis'. This is called a 'Schmitt trigger'.

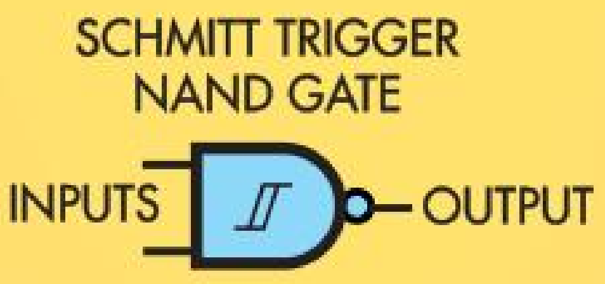
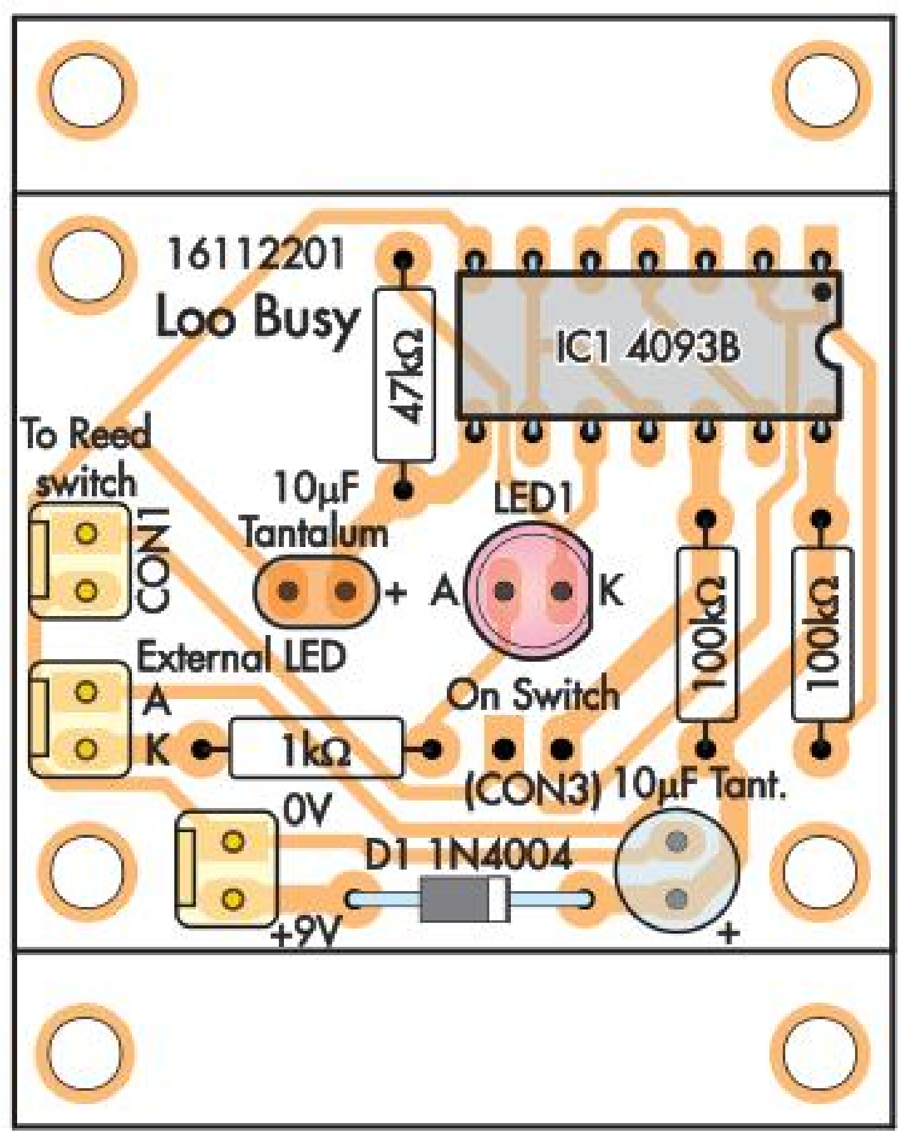
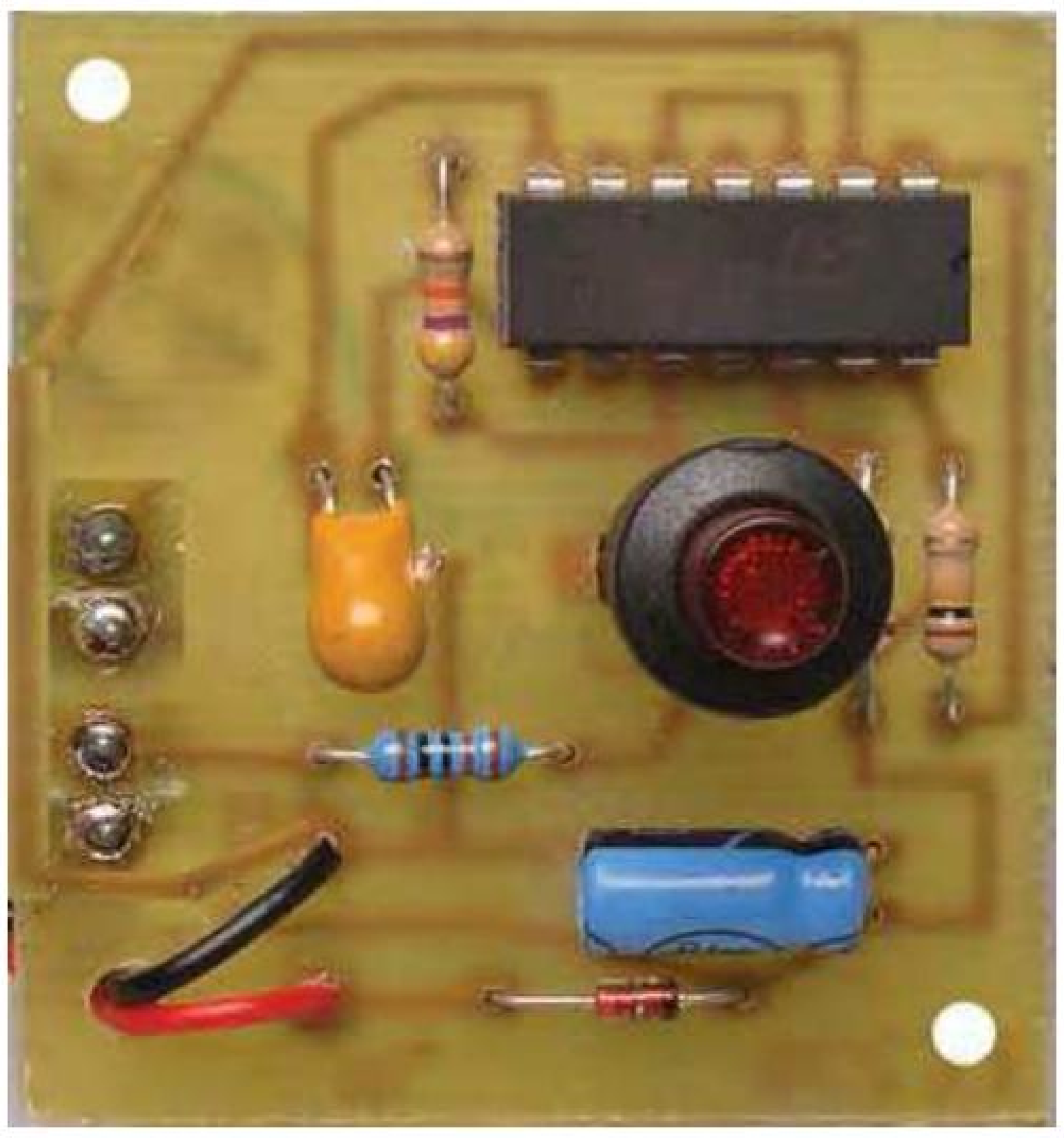


Fig.2: the PCB component overlay will help you place the components in the right positions. Watch the polarity of IC1, the diode and LED and both of the capacitors. This PCB is different from the photo at right in that it has 'extensions' on it to allow it to snap into place in the Jiffy box. These can be cut off if not needed.





The PCB photo is reproduced larger than life size. It is of an early prototype and there are some differences between the overlay and this board – for example, S1 and LED1 are both housed in the same bezel (you can use this type or a separate LED and switch). Also in this case, the battery connector is 'hard wired' to pads on the board and using the hole at lower left for strain relief.

electrolytic was used. Either is fine – but the other 10µF capacitor (on pin8 of IC1c) should be a tantalum.

Construction

There are only ten components to solder to the PCB and only five of these are polarised: the 4093B IC, of course, the on-board LED, the 1N4004 diode and the two capacitors. Fit the resistors first – if you can read resistor colour codes (see the parts list) that's great, but we do recommend you always check with your multimeter set to ohms, just to confirm their value.

In the case of the tantalum capacitors, the '+' marked on their body goes to the '+' mark on the PCB. ('Ordinary' electrolytics have the '–' leg marked; this of course goes to the '–' mark on the PCB).

Similarly, make sure the stripe on the diode aligns with the stripe on the PCB. Finally, note the notch on the end of the quad gate IC: it goes closest to the right edge of the board.

The anode of the internal LED is the longer of the two leads – again, it goes to the 'A' marked on the PCB.

S1, the 'start' switch, should be soldered direct to the PCB.

The reed switch and external LED both connect via thin insulated wires to their respective screw terminals on the PCB (reed switch to CON1; LED to CON2). Watch the LED polarity – make sure the anode connects to the A marking on CON2.

Before drilling the case and mounting the completed PCB, connect the 9V battery and check operation. Hold the door magnet close to the reed switch, then press S1. Both LEDs should start flashing; move the magnet away from the reed switch and they should stop flashing.

If none of this happens, check your component placement, orientation and soldering. With so few components, there is very little else that could go wrong. If all else fails, measure the battery voltage when the circuit should be on. It should be at or very close to 9V.

Mounting the PCB

The board sits upside-down in the jiffy box – the board is designed to snap into the captive guides on the box sides. You'll need to drill holes in the bottom of the case (which becomes the top!) for the 'start' switch (and internal LED).

If the start switch is soldered directly to the PCB, you need to be quite accurate with the hole placement.

Another hole is needed in the top of the case (which becomes the bottom!) for the wires to go off to the reed switch and to the door LED.

Mounting the door hardware

The exact location of the warning LED is entirely up to you – whatever gives the best visibility.

That might be actually through the door, or it could be on the door jamb. A wide variety of LED bezels is available, some of which are designed to work through a door or jamb.

Or you might simply glue the flat base of an ultrabright LED to the outside of the door, with a couple of fine holes for its leads/wires.

The reed switch and its magnet need to be placed so that when the door is

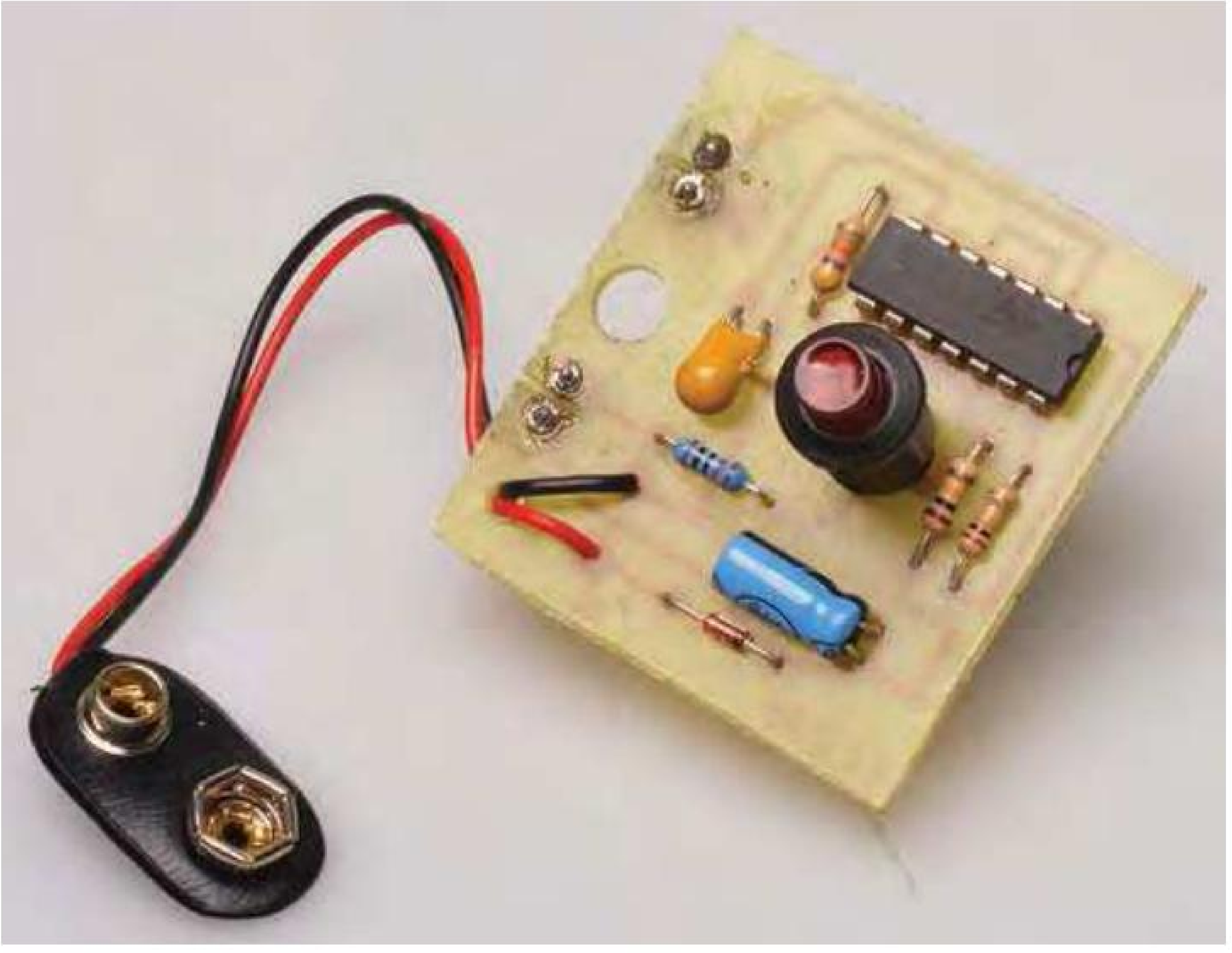
Parts List – Busy Loo Warning

1 PCB, 38.5 x 49mm; code 16112201, available from the PE PCB Service
1 UB5 Jiffy case, 83 x 54 x 31mm [eg, Jaycar HB6025]
1 reed switch set (reed switch and magnet – often sold for alarm systems – eg, Jaycar LA5027)
1 small momentary contact pushbutton switch (S1) #
2 mini PCB mount connectors
1 4093 quad Schmitt NAND gate (IC1)
1 1N4004 diode (D1)
1 ultrabright red LED [eg, Jaycar ZD0102]
1 standard red LED #
Suitable mounting for internal and external LED
1 9V battery snap
1 9V battery

Capacitors
2 10µF 16V tantalum

Resistors (0.25W, 1%)
2 100kΩ
1 47kΩ
1 1kΩ

# we used a pushbutton switch with an integrated LED; provision is made on the PCB for this or for separate switch and LED.



The battery snap wires are quite thin, so they go through a strain-relief hole in the PCB before soldering to their respective pads. As mentioned in the text, the capacitor at lower right is specified in the parts list as tantalum but here, a standard electrolytic is adequate. The other capacitor (the yellow component) should be tantalum due to their lower leakage.

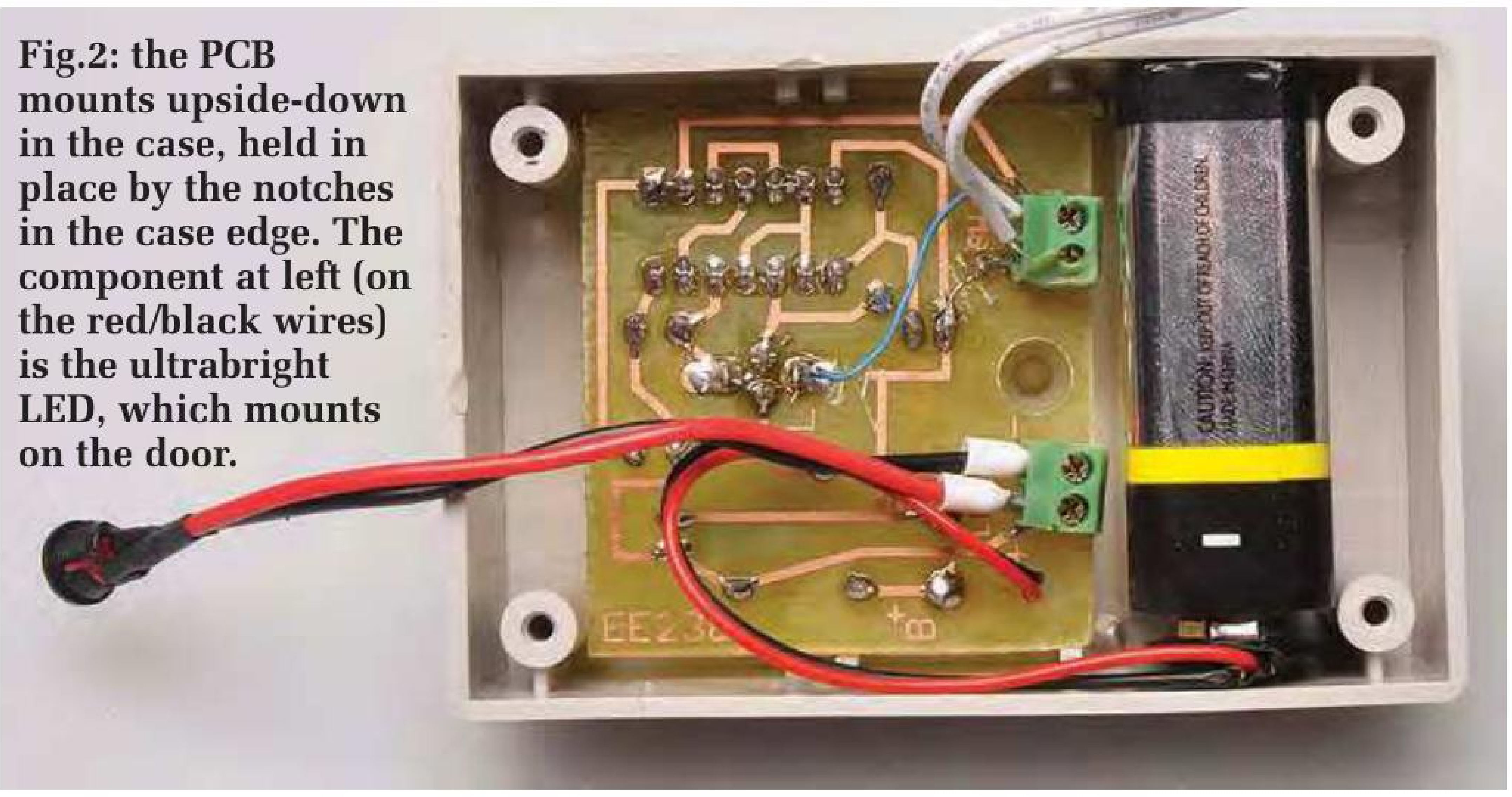
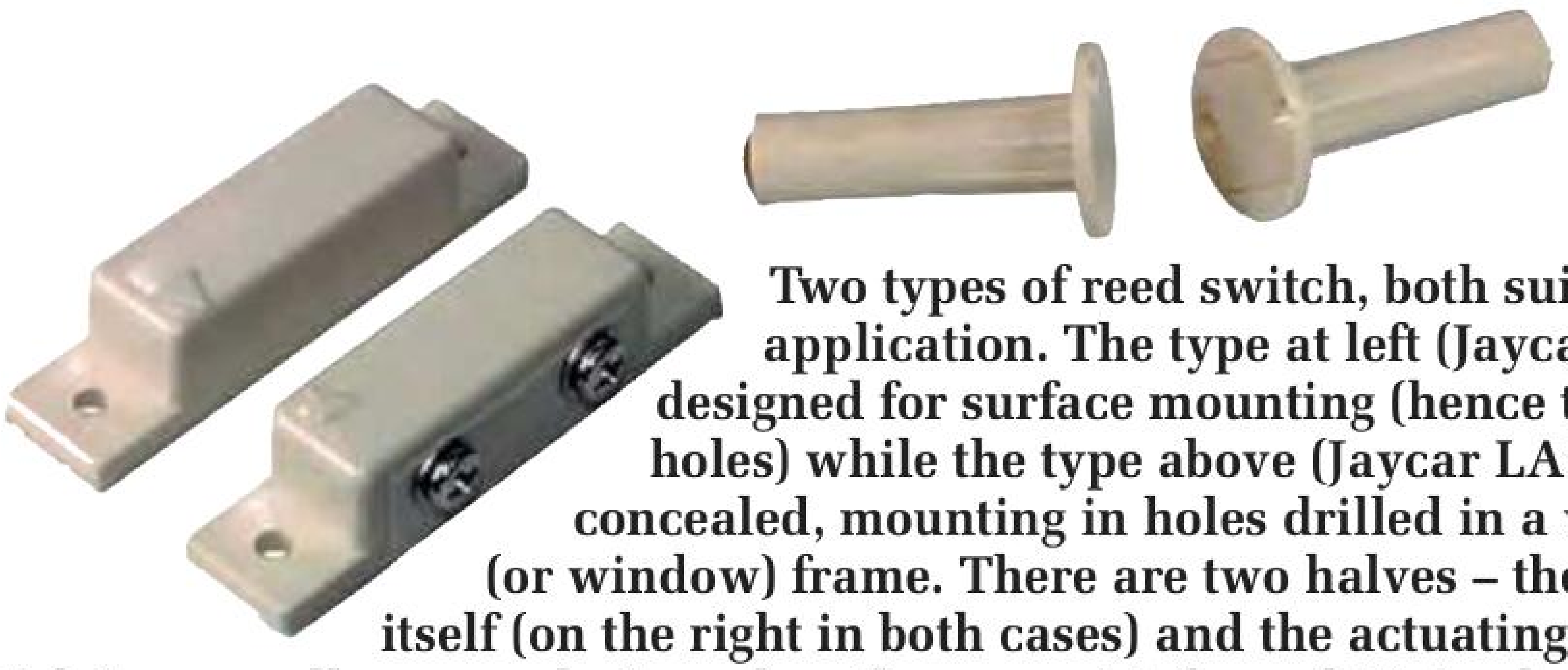


Fig.2: the PCB mounts upside-down in the case, held in place by the notches in the case edge. The component at left (on the red/black wires) is the ultrabright LED, which mounts on the door.

closed, the magnet comes very close to the reed switch (without hitting it!). It's probably best to have the reed switch on the door jamb and the magnet on the door. There are handy reed switch sets which come in plastic holders with screw holes, intended for alarm systems (eg, Jaycar LA5027). There are others which are intended for completely concealed mounting – the reed is recessed into the jamb and the magnet mounts inside the door. (eg Jaycar LA5075).



Two types of reed switch, both suitable for this application. The type at left (Jaycar LA5072) is designed for surface mounting (hence the mounting holes) while the type above (Jaycar LA5075) is fully concealed, mounting in holes drilled in a wooden door (or window) frame. There are two halves – the reed switch itself (on the right in both cases) and the actuating magnet. The switch is normally open, closing when the magnet is brought into close proximity.

Using it

That is simplicity itself! When you go into the loo, you simply press the momentary action (ie, normally open) 'Start' switch (S1). This starts both LEDs flashing (the internal LED assures you that you don't have a flat battery).

It stays that way until you open the door to leave. As the magnet moves away from the reed switch (S2) it opens, turning off the circuit – ready for the next occupant.

The 'automatic' reed switch turnoff is included because of the high likelihood that someone will forget to manually turn it off, resulting in a queue at the door of an unoccupied facility!

We could have made it fully automatic (ie, LEDs start flashing as soon as you entered) but deemed the extra complication not worthwhile. But for experimenters, it wouldn't be hard to do.

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Battery Monitor Logger

Part 2 – By TIM BLYTHMAN

16-11-2020 15:25:39
0%
0%
1= 0.00A Ah since full= 0.0Ah
2= Ah since empty= 0.0Ah
3= 0.00A Wh since full= 0.0Wh
4= 0.01A Wh since empty= 0.0Wh
Data
Settings
Calibrate

• Monitor up to 3 batteries from 6 to 100V • Currents to 10A (or 100A+ with shunt)

In *Part 1* of our new *Battery Multi-Logger* last month, we described how it combines the functions of a *Micromite LCD BackPack* with voltage and current-sensing hardware, plus power-saving techniques, all on a single PCB. Now we'll go over the construction, testing, setup and calibration procedures so you can build and use it.

Before starting the assembly, let's quickly review the *Battery Logger's* capabilities.

- It can handle batteries from 6-100V and monitor up to three bidirectional currents of up to 10A using its onboard shunts, or much more (to 100A or beyond) using external shunts.
- Its own power consumption is less than 1mA while actively logging with the screen off.
- It can display current and historical data on a 2.8-inch backlit LCD touchscreen, and the data can also be downloaded to a computer over USB for further analysis.
- It tracks the current battery state-of-charge in both amp-hours (Ah) and watt-hours (Wh), and it has a current measurement resolution of around 0.1% of full-scale, which equates to 10mA steps when using the internal shunts.

All these functions are built onto a small PCB. All the user interface features are accessed via the touchscreen, so it can easily be integrated into other devices with a rectangular case cutout.

Construction

The *Battery Logger* is built on an 86mm x 50mm double-sided PCB coded 11106201, available from the *PE PCB Service*. Fig.5 shows where the components go, on both sides of the board.

As usual, when assembling a board with many SMDs, it is useful to have the following on hand: flux paste, solder braid (wick), a magnifier, tweezers and an adjustable temperature iron. The smallest parts have pad spacing under 1mm, so solder bridges are almost inevitable, hence the need for flux paste and solder wick.

Since flux tends to generate smoke, use a fume extraction hood or work in an outdoor area, where the smoke can more easily dissipate.

One of the most fiddly parts is the USB socket (CON5) so start by fitting that. Dispense flux onto the pads and then sit the USB socket in place; it should lock into the holes in the PCB. Add more flux to the tops of the pins.

With a clean tip, add solder to your iron, then press it against the small pins and pads together. The socket's metal shroud tends to get in the way a bit.

Once you are sure that you have soldered all the pins, check for bridges and remove them if necessary, then solder the larger tabs on the shroud in place.

ICs

Solder the ICs (IC1-IC6 and REF1, on the back of the PCB) next. We suggest fitting IC5 first, as it has the finest pin pitch.

For each of the ICs, check the orientation of pin 1 against the PCB silkscreen by matching the dot before soldering any pins.

IC6 is asymmetric, so although this part is small, it is easy to orientate correctly. Note that some of the ICs might not have a dot to indicate pin 1. Instead, they will have a bevel along one edge or a line at one end; in each case, this feature is nearest to pin 1. For REF1, the pin 1 indicator might even be a tiny laser-etched cross.

When soldering the ICs, apply flux to the pads, then rest the IC in place and tack one lead. Check the positioning, ensuring that the part is flat and aligned within its pads. If not, remelt

SILICON CHIP
27
BATTERY MULTI-LOGGER
27-11-2020 12:00:20
OK
CHGv= 56%
CAP=
0.0Ah
V= 12.89V
CHGm= 0%
CAP=
0.0Wh
I1= -0.04A
Ah since full=
-2.4Ah
I2= -0.09A
Ah since empty=
-2.4Ah
I3= -0.12A
Wh since full=
-30.7Wh
I4= -0.06A
Wh since empty=
-30.7Wh
Data
Settings
Calibrate

The Multi-Logger can be mounted in a UB5 Jiffy Box like many Micromite-based projects, as shown here. But you might like to use the bezel to mount the Multi-Logger in the front panel of your equipment enclosure; you could then use the Jiffy Box to protect the rear of the unit.

the solder and adjust the part with the tweezers.

After the part is located correctly, solder the remaining pins. Don't worry about solder bridges as they happen, as it is easier to remove multiple bridges later, all at the same time. Apply extra flux if necessary during soldering.

To remove any bridges, apply fresh flux and press the solder braid against the excess solder with the iron. When it melts, allow it to draw up the solder and then gently pull it away from the component.

The surface tension between the component and the pad should hold enough solder to maintain a good connection, even if the solder braid removes most of it.

Now is a good time to inspect your work closely with a magnifier, as making changes will be harder as more parts are added.

It's a good idea to clean away excess flux first; isopropyl alcohol is a good all-round choice, but specialised flux cleaning products often do a better job.

Transistor and regulators

The next trickiest parts are the transistors and regulators in SOT-23 packages. There are six such parts in three types: Q1 and Q3 (P-channel MOSFETs), Q2 and Q4 (N-channel MOSFETs), and REG1 and REG2 (LDO regulators).

Fortunately, they will only fit one way, so use a similar technique to the ICs. Solder one lead and check the position before soldering the remaining leads. The rest of the SMDs all have much larger pads, so are easier to deal with.

Resistors and capacitors

Many of the remaining parts are 3216-sized (3.2 x 1.6mm; or 1206 imperial) resistors and capacitors. The resistors should be marked with their values, while the capacitors are typically not, so take extra care with the capacitors and don't mix them up. (We recommend working with one value at a time.)

Where possible, we've marked the resistors and capacitor values below the part itself; the exception is the parts around IC4.

Remember that if you are using external shunts for current sensing, you omit the three 15mΩ shunt resistors. Leave the larger shunt resistors aside for now, even if you intend to fit them. For the remaining parts, check the value printed on the silkscreen against the value on the part, which will be a numerical code that you can match in our parts list.

For each part, apply flux to the pad, solder one lead, check and adjust if necessary and then solder the other lead. Refresh the first lead if necessary.

Most of the capacitors are 100µF, 10µF or 100nF types, so we recommend placing these first. The 100µF and 10µF capacitors will most likely be larger, so they won't be too hard to differentiate. All four 100µF devices are fitted to the back of the PCB.

Use the same method as for the resistors. Follow up with the remaining capacitors, taking note of their value before removing from the packaging and working one at a time.

There are two small inductors (L2 and L3) which also have 3216 dimensions; they are soldered in much the same way.

The larger 120µH inductor (L1) might require a hotter iron to solder. Use the same technique of working on one lead at a time. Sometimes you get better heat transferral by pressing the long edge of your soldering iron tip onto the pad. Then solder the other lead.

Next, solder the button cell holder. Again, you might need to turn up your iron to supply more heat. Add flux to the pads and locate the holder such that a cell can be inserted from the edge of the PCB.

Tack one pad down and when you are happy with it, solder the other pad. Refresh the first pad to relieve any stress on the PCB pads. Check our photos to see how it should look.

And the rest

There are two surface-mounted diodes; they are both fitted with their cathodes facing towards REG2 (as that is what they supply).

You may well be using surface-mounting or through-hole parts for LED1 and S1. Fit these two next. LED1's cathode faces to the right, towards CON1. Most surface-mount LEDs have their cathode marked with a green dot, but double-check this, as some do not.

At this stage, practically all the SMDs have been fitted, so it is a good opportunity to clean off any excess flux left on the PCB.

JP1 is not usually needed, so can be left off (we used it in our testing), but JP2 is required. Fit the jumper shunt to make it easier to manipulate and solder one lead. Check it is square and flat, then solder the other leads.

If you have pre-programmed microcontrollers (IC1 and IC2), then fit the shunt to JP2 on the bottom two pads (as seen in our photo). This is the 'RUN' position. If you need to program IC1, then fit the shunt to the top two pads (near the PCB mounting hole).

For programming, you will only need to fit CON1, as IC2 can program IC1. But if you have a programmer, you might find it quicker and easier to fit both for programming anyway.

We used right-angled headers for CON1 and CON2 to make it easier to debug, but straight headers will also work, and fit under the LCD.

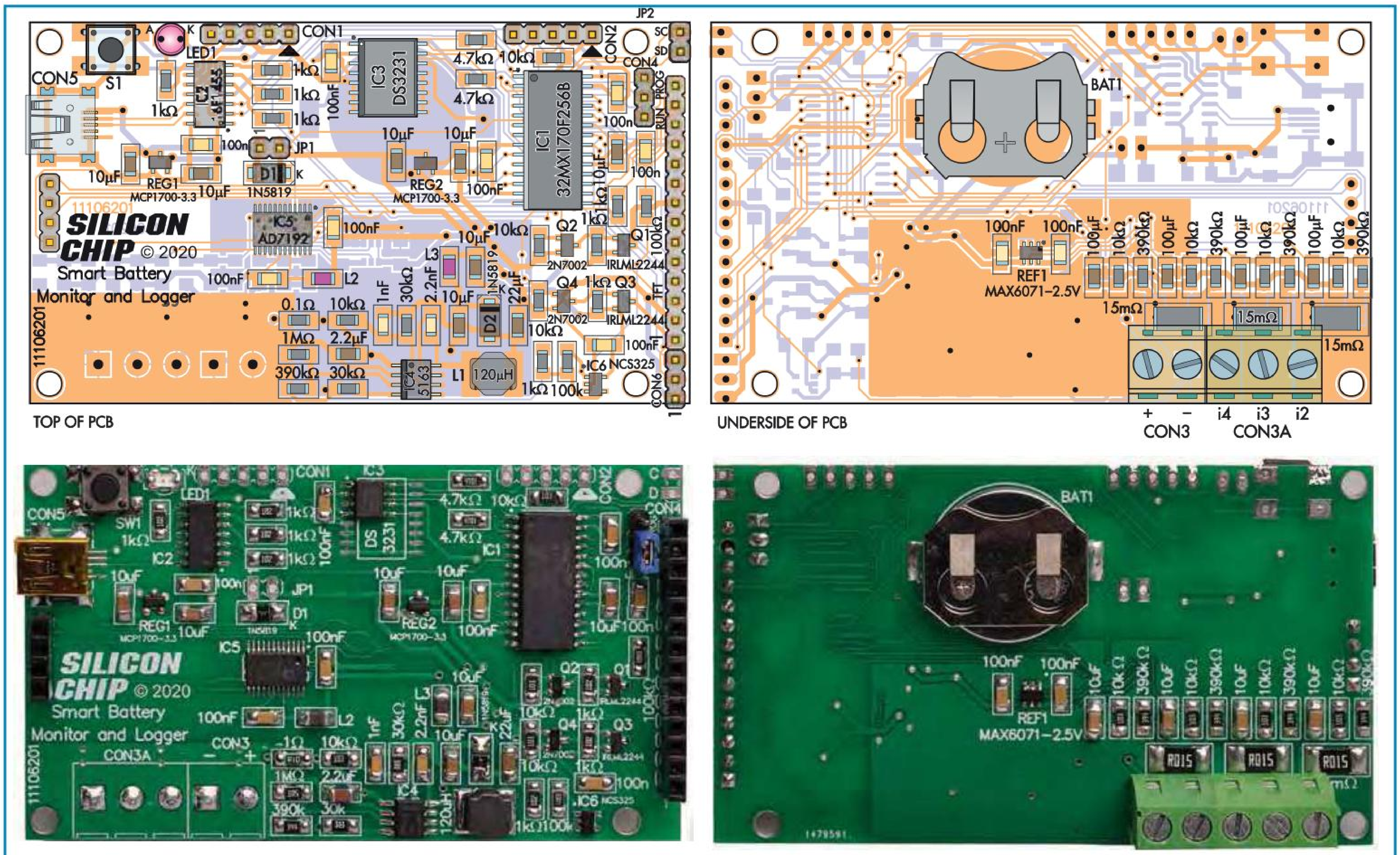


Fig.5: the PCB photos shown above are of an early prototype, so they differ slightly from the overlays which are our final design, including up-to-date component values. There are components on both sides, although the back of the board is much more sparsely populated. Take extra care with the orientation of all ICs, the two diodes and the LED. Most of the other components are unpolarised.

The connections for the 2.8-inch LCD are made up of a 4-way and a 14-way female header. Only the 14-way header is needed for the current version of the software, although having both headers will make the assembly more robust.

Use the 2.8-inch LCD as a jig to fit the headers. You might need to solder pin headers to the LCD if they are not pre-installed; most do not come with the 4-way header fitted. In that case, plug the headers into the sockets and insert them into their respective PCBs. The headers sockets go on our PCB, with the pin headers on the LCD side.

Solder the headers in place, keeping the PCBs parallel. Then gently separate the LCD from the PCB, wiggling it if necessary.

The final step in assembling the PCB is to fit CON3 and CON3A, the battery and load connections. Mount them on the back of the PCB to allow access even after the stack is assembled. Verify that you have fitted the three larger 15mΩ shunts if you will not be using external shunts.

Programming

If you have pre-programmed ICs, you don't need to worry about this step and should proceed to the setup section. Both IC1 and IC2 need firmware to work. The only way to program IC2 in-circuit is to use ICSP header CON1 and a programmer such as a PICkit 3 or PICkit 4.

You can use the MPLAB X IPE (integrated programming environment), which is available as a free download as part of the MPLAB X package from: **www.microchip.com/mplab/mplab-x-ide**

Choose PIC16F1455 as the device and your programmer from the Tool drop-down. Connect the programmer to CON1 according to its instructions and browse for the Microbridge HEX file (**2410417A.HEX**). Then press the Program button to upload it.

With the IPE open, you can also use this to upload the firmware for IC1. Connect the programmer to CON2, select PIC32MX170F256B as the Device and browse for **1110620A.HEX**. Upload this file with the program button.

After programming is completed, don't forget to move JP2 to the RUN (lower) position.

Microbridge and MMBasic

If you're inclined to tinker with the BASIC code, you can program IC1 with the MMBasic files too, although that is a bit more involved.

We'll outline the steps, but with the assumption that you do have a bit of experience with the Micromite environment, know your way around MMBasic quite well and are comfortable uploading files to the Micromite. If you don't want to do this, then skip to the next section.

You will need the Microbridge firmware on IC2 and start with JP2 in the PROGRAM position, as it needs (at the very least) the HEX file for the BASIC environment to be uploaded to IC1 first.

This can be done with a PICkit and the IPE (as outlined above), but instead of the *Battery Logger* firmware, you should choose the latest Micromite MMBasic firmware file.

Alternatively, the MMBasic firmware can be uploaded by the Microbridge by pressing S1 (to enter programming mode). Then use a program like pic32prog or P32P GUI to upload the Micromite MMBasic HEX file. We used version 5.5.2.

JP2 can now be moved to the RUN position. From the BASIC environment (a serial port running at 38,400 baud), you should run the commands to set up the 2.8-inch LCD and touch panel as per usual for the *V2 Micromite BackPack*.

```
OPTION LCDPANEL ILI9341,
  LANDSCAPE, 2, 23, 6
OPTION TOUCH 7, 15
GUI CALIBRATE
```

The BASIC files are arranged as a library file supplementing the main source code. This allows the Micromite to compress some of the data it uses. Load the **Library.bas** file, then run the command:

```
LIBRARY SAVE
```

This saves and compresses the library file. Next, load the main **Battery Logger.bas** file and run it. These instructions are in the **Library.bas** file.

Setup and operation

If you haven't already done so, fit a CR2032 cell to the BAT1 holder, fit the LCD panel and connect the Logger up to a computer or USB power supply via CON5. If you programmed IC1 with the hex file specific to this project, then the Logger software should start straight away. If you loaded the BASIC files yourself, you might need to run the program manually for the first time.

You should see Screen1 appear at startup. An error message might appear for the first few seconds while the program waits for a valid battery reading to occur; if it does not disappear after about ten seconds, there could be a problem with IC5. The voltage shown after 'V=' should be zero, as you don't have a battery connected yet.

You might see some readings for the current values, though, as we have not completed the calibration yet. I1 corresponds to the Logger's own current use, while I2-I4 are the currents measured through the terminals of CON3A, as shown in Fig.5. These values might jump around a bit, but the long-term averages are the most important figures.

At right are the capacity and state of charge measurements. CHGv% is a simple linear calculation between nominal full and empty voltages, while CHGm% is based on measured current since the last full and empty states.

The CHGm% reading won't be entirely accurate until the battery has experienced a complete charge and discharge cycle. Similarly, the capacity readings will not be meaningful right away.

At upper right is a countdown timer; when this reaches zero, the display will blank. This is the normal mode, where the *Battery Logger* is logging, but does not need to display anything, thus saving power. The counter can be reset by touching anywhere on the Main screen.

This timeout only happens from the Main screen shown in Screen1, so make sure to return to it each time you finish accessing the *Battery Logger's* graphical interface.

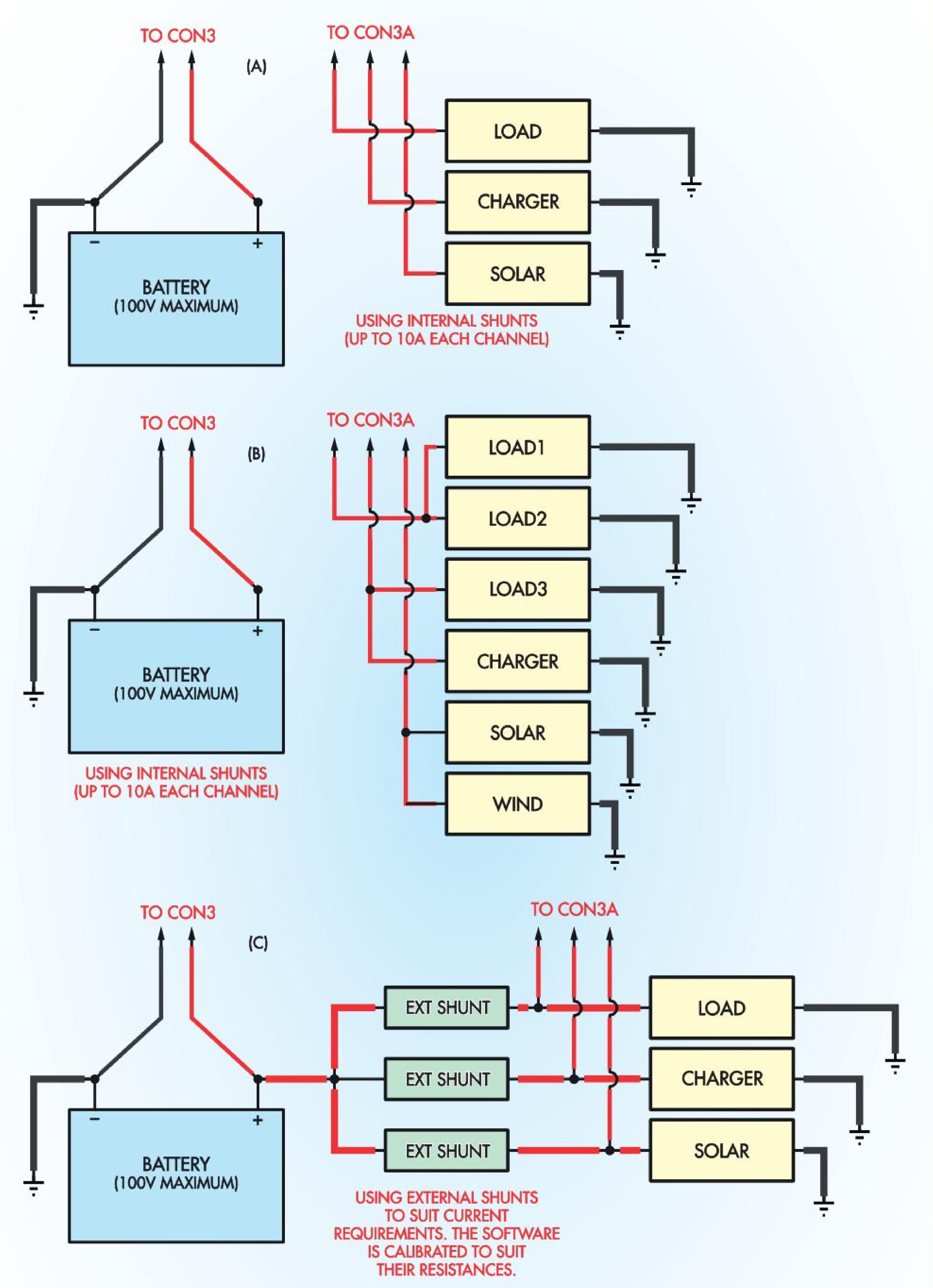


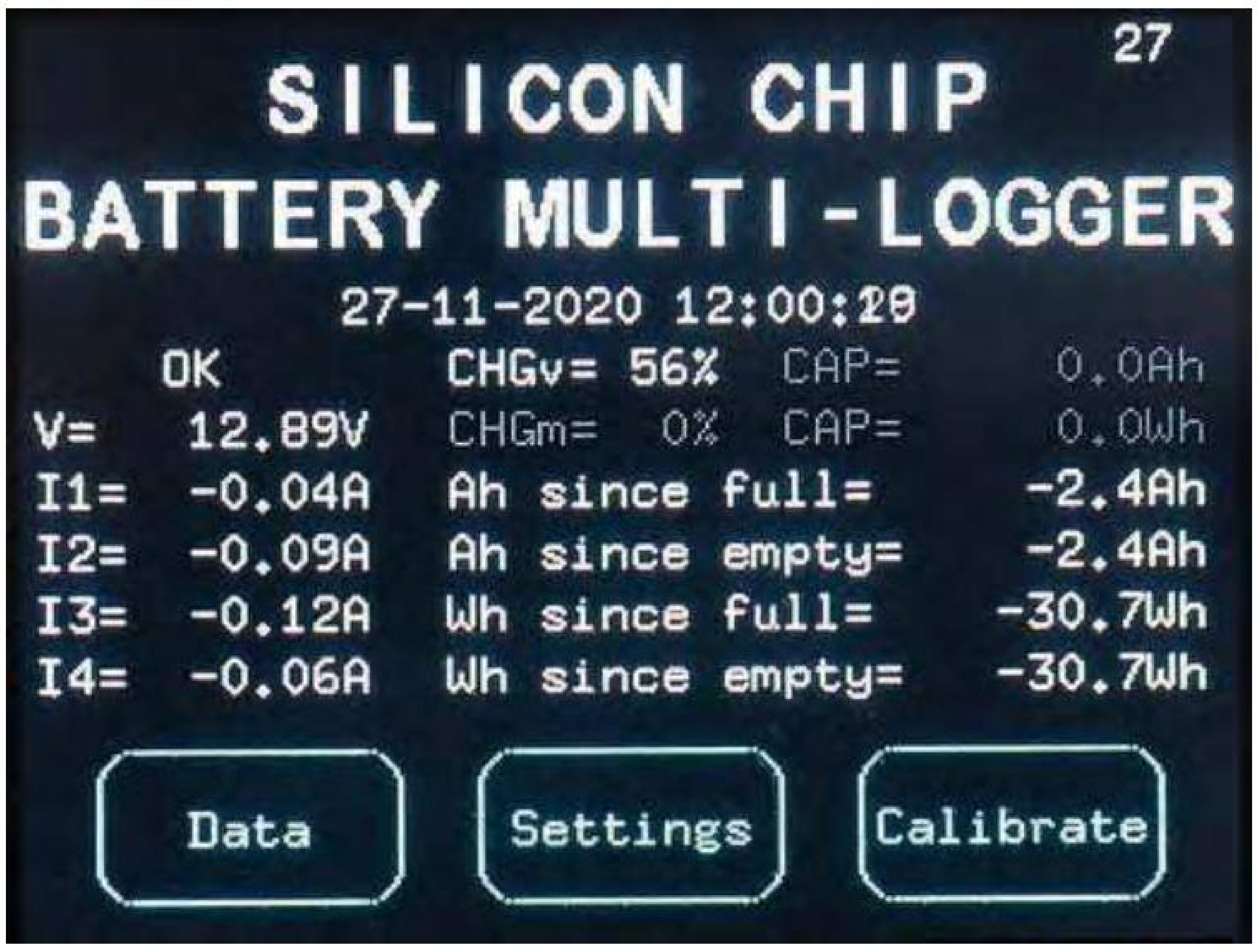
Fig.6: we ran this diagram last month to show what the Logger can do. We're repeating it now as you might want to use it as a guide when wiring it up. When using the internal shunts, the battery connects across CON3, and the positive ends of your loads or chargers go to the terminals of CON3a. All load and charger negatives go straight to the battery. When using the external shunts, follow diagram (C) and make sure the wiring from the battery to the shunts is short and thick for maximum precision.

To reactivate the screen, press and hold the touch panel until the backlight illuminates. For maximum power efficiency, the Micromite only checks the panel at one-second intervals, so it might take a second or so of touch to wake it up. The *Battery Logger* waits for the touch to be released before displaying the main screen, so you can't accidentally press a button when waking it up.

The interface is fairly intuitive, but we'll walk through the various screens anyway. Screen2 is reached by pressing the Data button and displays a graph of the voltage and currents. The current scale (left-hand side) can be manually set, while the voltage scale uses the nominal full and empty values. By default these are set to 14.4V and 11.0V, to suit a 12V lead-acid battery.

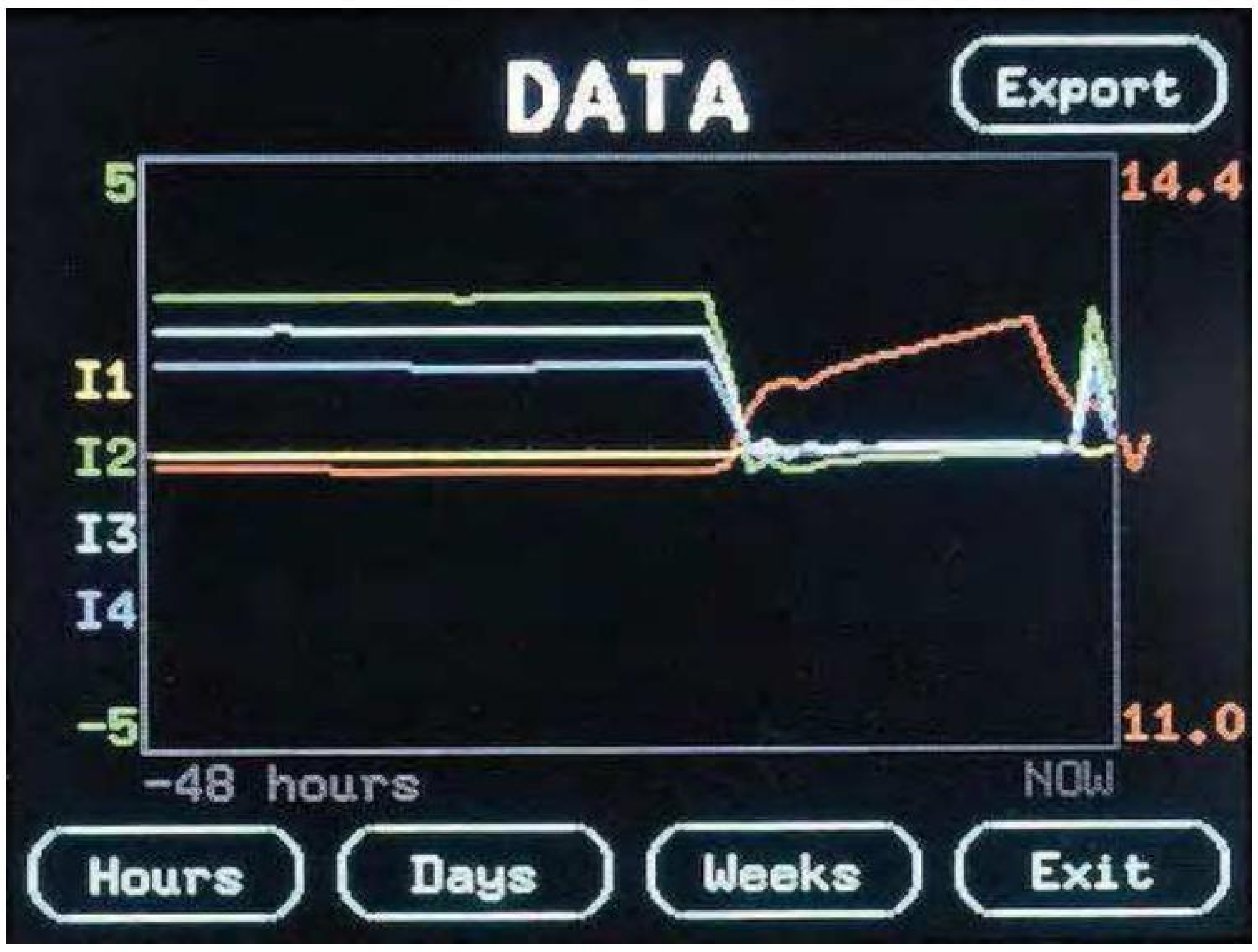
The buttons along the bottom set this page to display the various scales, with the time frames shown at the bottom of the screen. In each scale, the Export button does a dump of data to the serial port. This data is produced so that it can be saved as a CSV (comma separated value) file and then can be opened with most spreadsheet programs. Pressing Exit returns to the Main display.

Screen3 is accessed using the Settings button. Each value shown can be changed by pressing the respective button.



```
                                  27
         SILICON CHIP
   BATTERY MULTI-LOGGER
      27-11-2020 12:00:28
   OK     CHGv= 56%  CAP=      0.0Ah
V=   12.89V  CHGm=  0%  CAP=   0.0Wh
I1=  -0.04A  Ah since full=   -2.4Ah
I2=  -0.09A  Ah since empty=  -2.4Ah
I3=  -0.12A  Wh since full=  -30.7Wh
I4=  -0.06A  Wh since empty= -30.7Wh
```

Screen1: the main screen provides all the critical statistics for your battery, as well as three simple menu options for accessing other features. The greyed values seen are capacity calculations which are not yet valid, as the Logger has not detected a complete charge and discharge cycle; they will light up brighter when that happens.



Screen2: the Data screen provides a graphical view of the logged data. Different timespans can be shown, and the display will automatically scroll once a minute to show current data. The Weeks option provides around a fortnight of data. Data can also be dumped as CSV rows over the console serial port with the Export button.

Screen4 shows a number being entered, in this example to update the current year. If the number entered is invalid, a message is displayed. Pressing OK prompts for the new value to be confirmed (see Screen5).

The time and date settings are immediately saved to the real-time clock and are displayed on this and the main screen. The two B/L values are for the backlight brightness as a percentage, from 1-100. The first value (B/L) is used most of the time.

The second value (B/L dim) is used for the last five seconds before the screen shuts down, to indicate that this is about to happen. A minimum value of 1% is allowed for either setting to ensure that the display is always visible.

The V(full) and V(empty) values should be set to suit your particular battery. You can't set the V(empty) value to be higher than the V(full) value.

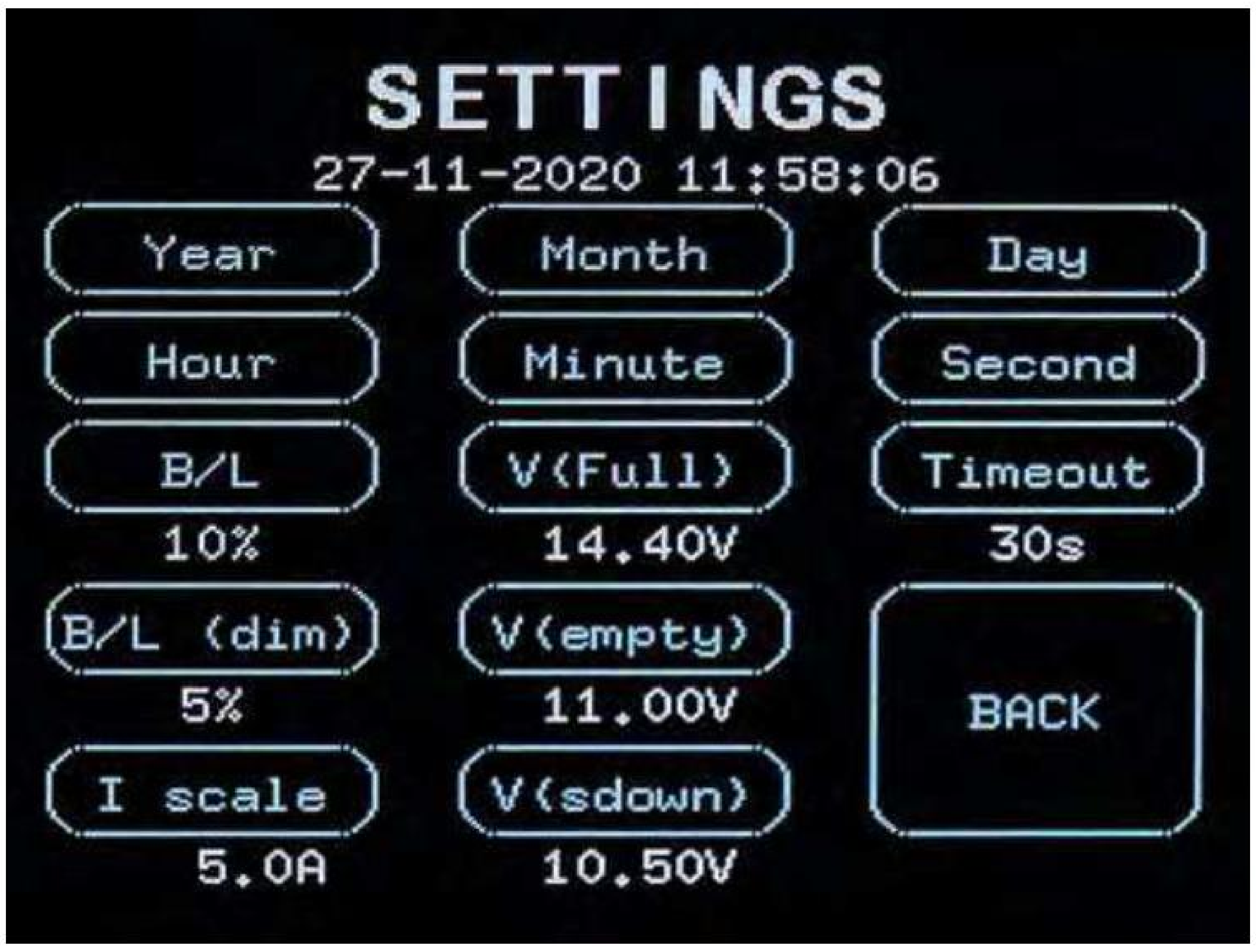
The Timeout value sets how long the display stays on before blanking at the Main screen. This has a minimum of five seconds, as this is the period of dimming that occurs before blanking. A large value can be used to stop the display blanking; eg, a period of 99999999 seconds is around three years.

The 'I scale' value sets the limits of the graph on the Data page only. Setting a value of 20 will cause the graph to span from –20A to 20A.

The 'V(sdown)' value sets a critical battery limit. Below this level, the *Battery Logger* sleeps for much longer periods between activity. The MMBasic code sets this to 15 seconds. Since the ADC (IC5) goes to sleep after each conversion, the result is that current consumption drops even lower than the normal 'screen off' mode.

This setting is intended to preserve a battery that already is heavily discharged. You can still use the *Battery Logger*, although you will have to touch the screen for up to 15 seconds to wake it up, and the data will be much more sparse, as it won't be logging as frequently. Still, you should be able to quickly identify that there is a problem with the battery and rectify it.

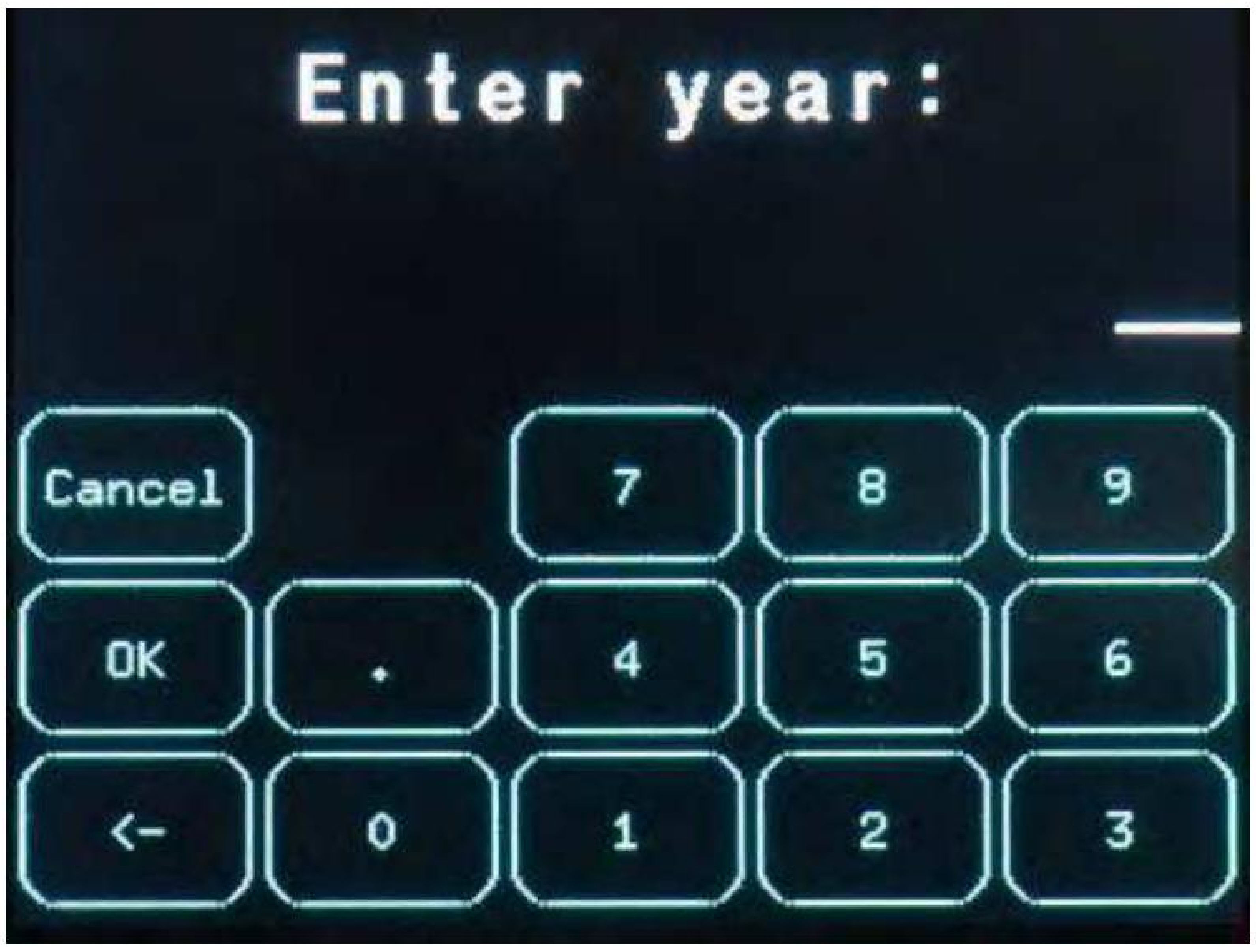
To disable this feature (eg, for testing without a battery connected), set this value to 0V. In this case, the buck regulator will shut down below



SETTINGS
27-11-2020 11:58:06

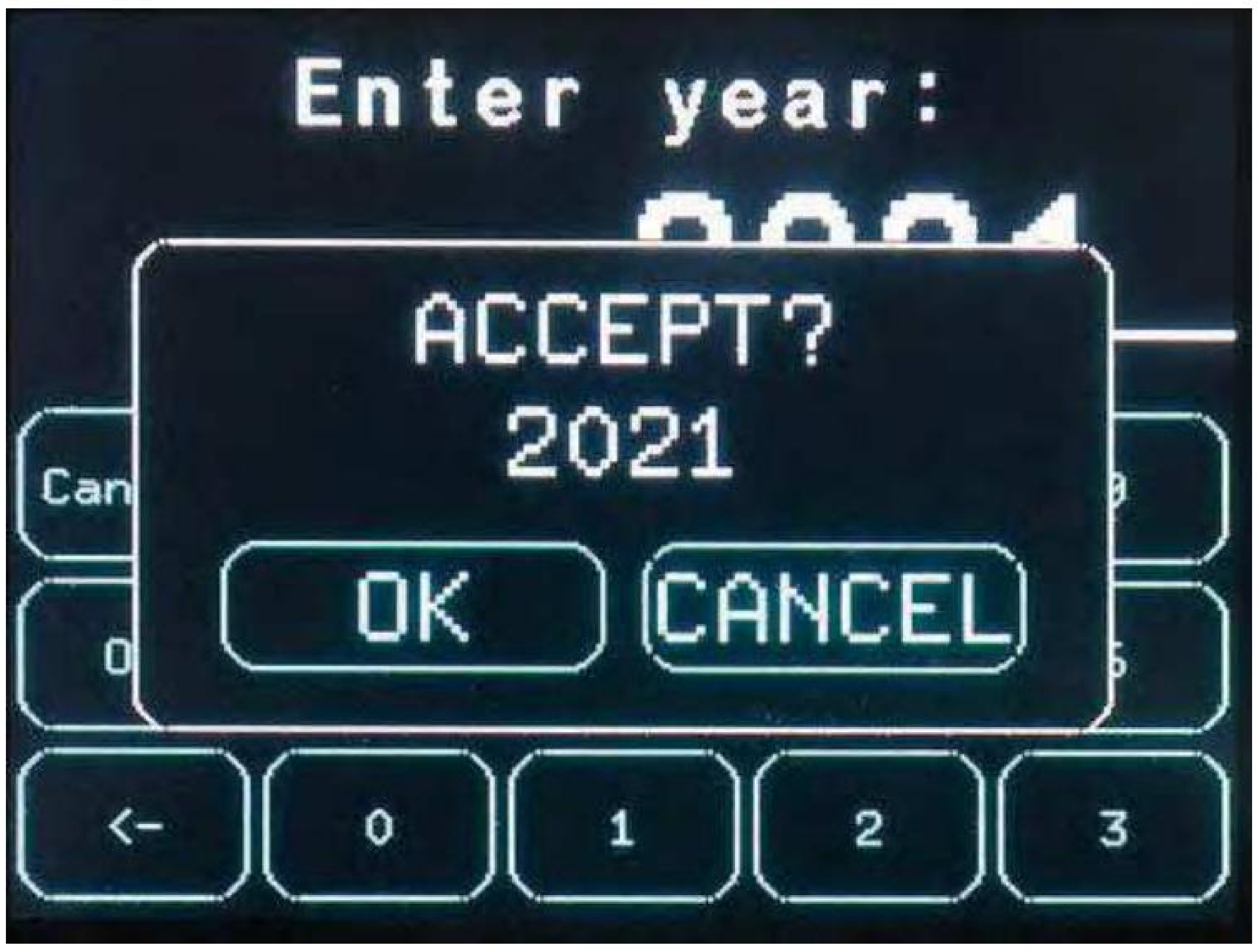
B/L 10%
V(Full) 14.40V
Timeout 30s
B/L (dim) 5%
V(empty) 11.00V
I scale 5.0A
V(sdown) 10.50V

Screen3: the Settings screen provides the most common options for configuring the Logger, including battery voltages, time and date and backlight controls. Each entry is validated to ensure it does not conflict with other values (such as the 'Empty' voltage being higher than the 'Full' voltage) and then immediately saved to Flash memory.



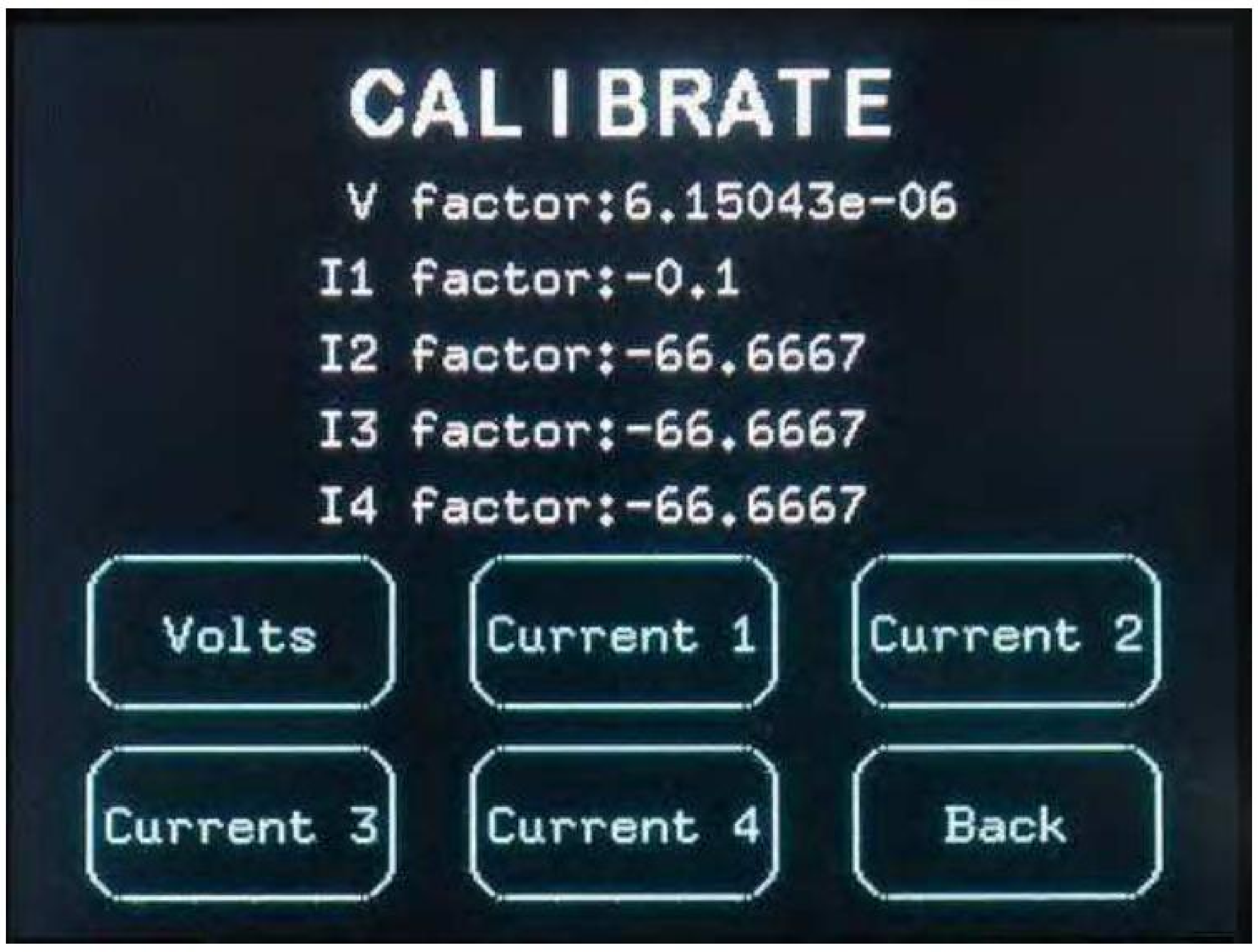
Enter year:

Screen4: the Entry screen is displayed whenever a number needs to be entered. The symbol at lower left allows the last typed character to be deleted. Since negative numbers are not used, there is no minus symbol.


Enter year:

ACCEPT?
2021

Screen5: each Entry value is validated before being processed and saved, which provides a way of safely making changes.


CALIBRATE

V factor:6.15043e-06
I1 factor:-0.1
I2 factor:-66.6667
I3 factor:-66.6667
I4 factor:-66.6667

Screen6: the Calibration screen provides a mostly automated way of adjusting the Logger to account for component tolerances. The operator simply needs to enter a meter reading (volts or amps), and the Logger calculates the calibration factors to produce the desired value.

around 5.5V, causing the *Battery Logger* to power off completely unless it is powered from USB.

Calibration

The remaining button on the Main page goes to the Calibrate page (Screen6). You should always calibrate the V factor first, as the measured current depends on the voltages measured being accurate.

Internally, there is a V factor (the ratio between the actual voltage and the raw 24-bit ADC reading) for each of the four dividers, but only one is displayed, as they should all be similar to within component tolerance. The nominal value is 100V/16,777,216; ie, a full-scale reading at 100V.

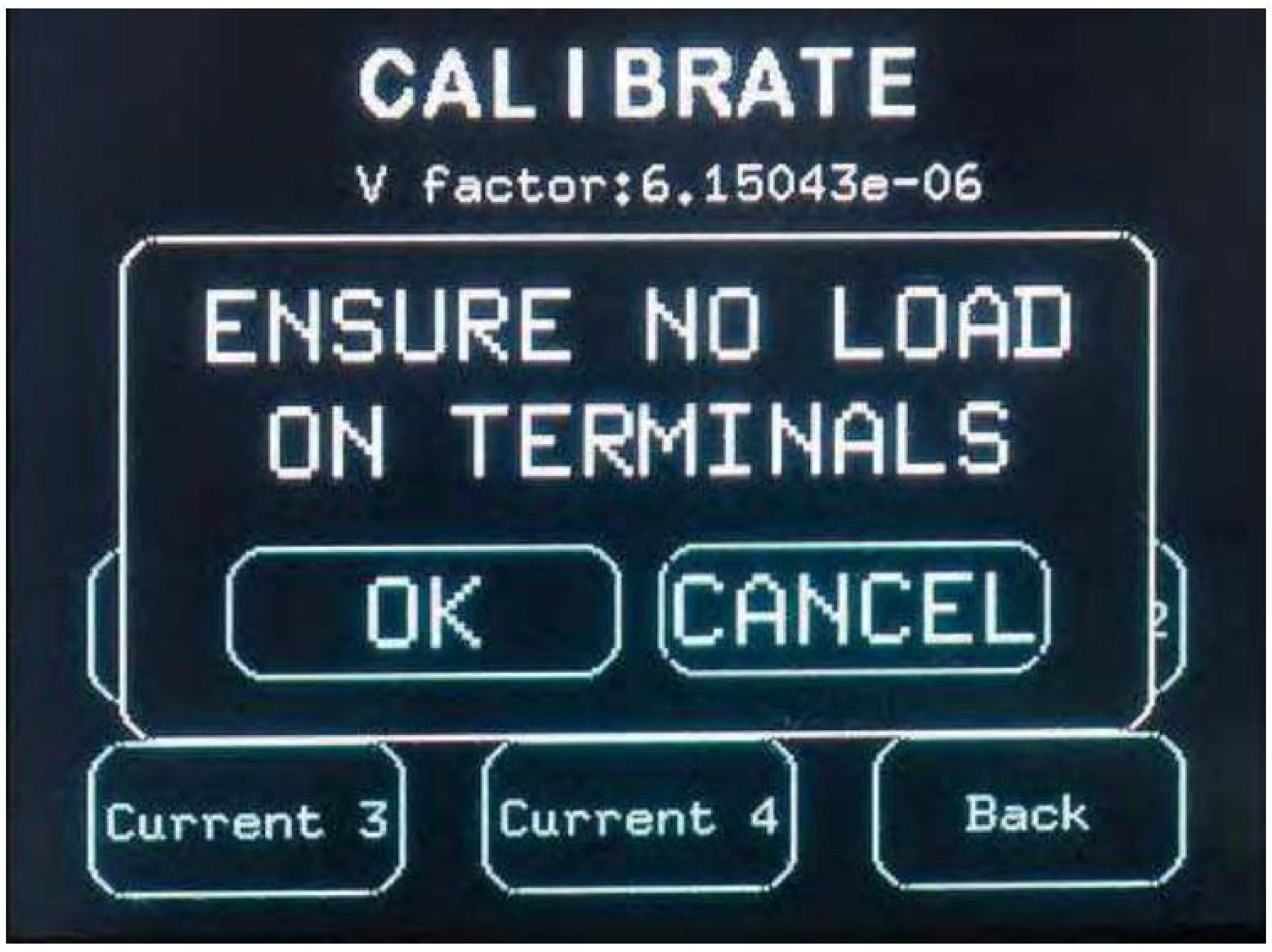
The four V factors allow compensation for variations in the dividers, mostly due to component tolerances. They allow the three current sense dividers to be zeroed against the primary voltage divider. Thus, this step should be done first before attempting to calibrate the individual currents; otherwise, there will be an offset from zero.

You'll need to hook up your battery, or, at the very least, a stable voltage source above 6V. Higher voltages will mean that the quantisation error (due to steps between consecutive ADC values) will be proportionally less, potentially giving slightly better calibration.

Don't hook up anything to CON3A though, as we don't want any current flow to skew the results. If possible, leave the USB supply connected too, as this will minimise the load on the battery, with the display running from USB power. In this case, the only battery drain will be the no-load quiescent current of IC4, at around 10µA.

Hook up a voltmeter to the battery terminals and allow the unit to settle for a minute. This reading must be stable for optimum results. Press the 'Volts' button and acknowledge that there is no load on the terminals.

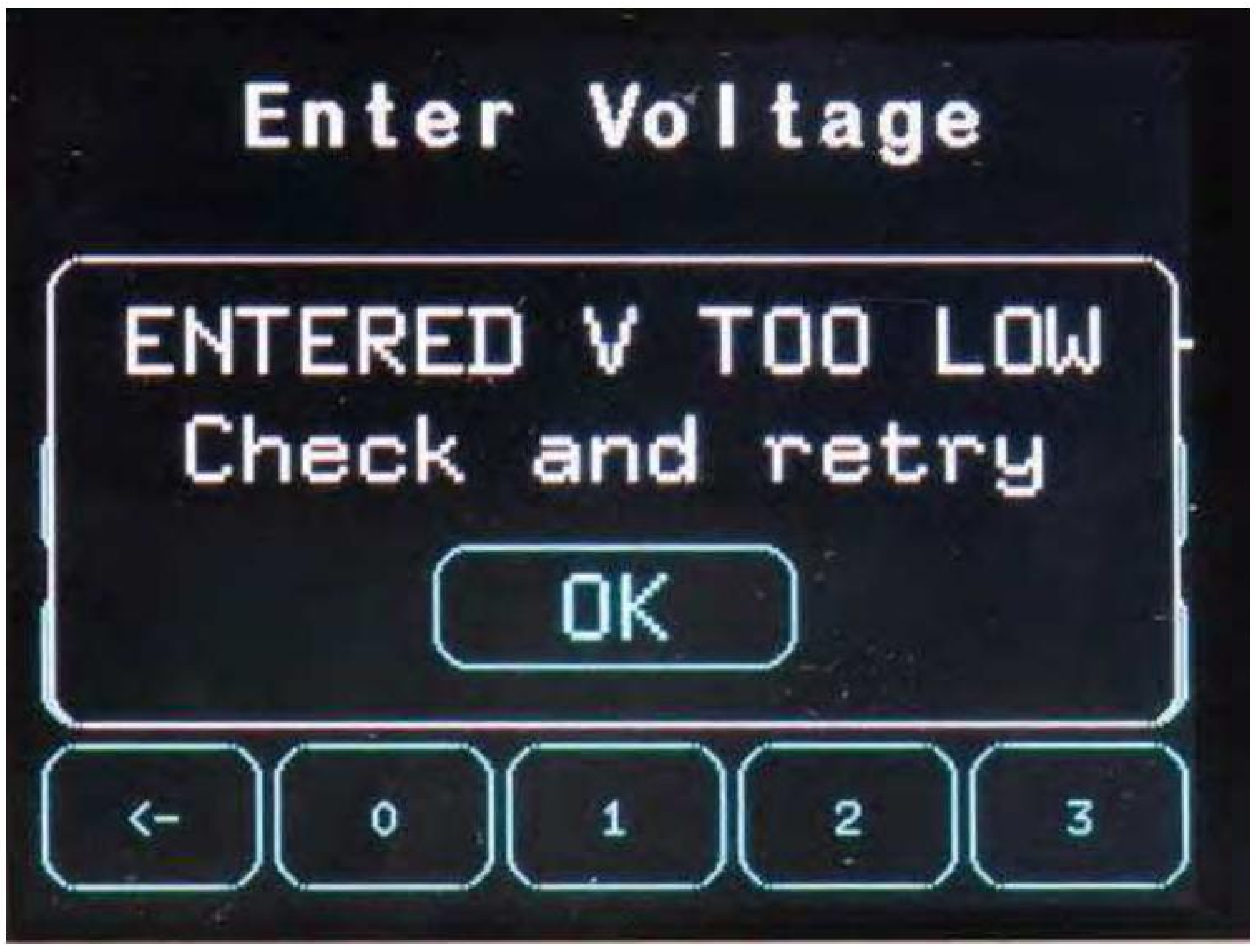
Enter the battery voltage as displayed on the voltmeter. A page will show the various V factors and an estimate of how much they vary. If there is a variation of more than a few percent (due to component tolerances), you might have a problem with the dividers, such as a wrong component value or a spurious load on the battery.


CALIBRATE

V factor:6.15043e-06

ENSURE NO LOAD
ON TERMINALS

Screen7: any conditions that need to be satisfied for accurate calibration are prompted before the calibration begins. While this adds an extra step, it means there is little chance for the calibration to fail.


Enter Voltage

ENTERED V TOO LOW
Check and retry

Screen8: as noted, all values are checked for validity before being saved and used by the Logger. In this case, a brief but helpful message is provided to allow the user to work out what went wrong.

You can confirm the new values by pressing OK, or use Cancel to investigate further. The calibration is stored to Flash and used immediately. Go back to check that the displayed currents (I2-I4) have settled near zero. This means that the calibration is correct.

The remaining calibrations are not so critical as they won't produce an offset in the results, but will simply give incorrect current scaling. The default values are calculated from nominal component values; you will have to change these if you are using external shunts.

Current calibration

The current calibration method is straightforward. A known load is applied to each terminal, the current is measured and entered into the *Battery Logger*, and it then calculates the conversion ratio.

For I2-I4, these are the external loads at CON3A, while I1 is the *Battery Logger's* own current. Thus for I2-I4, the load should be applied between CON3A and the battery negative.

In this case, the actual current being displayed on the main screen will be negative (the battery is discharging). Still, you can only enter a positive value, so you should just enter the magnitude of the current.

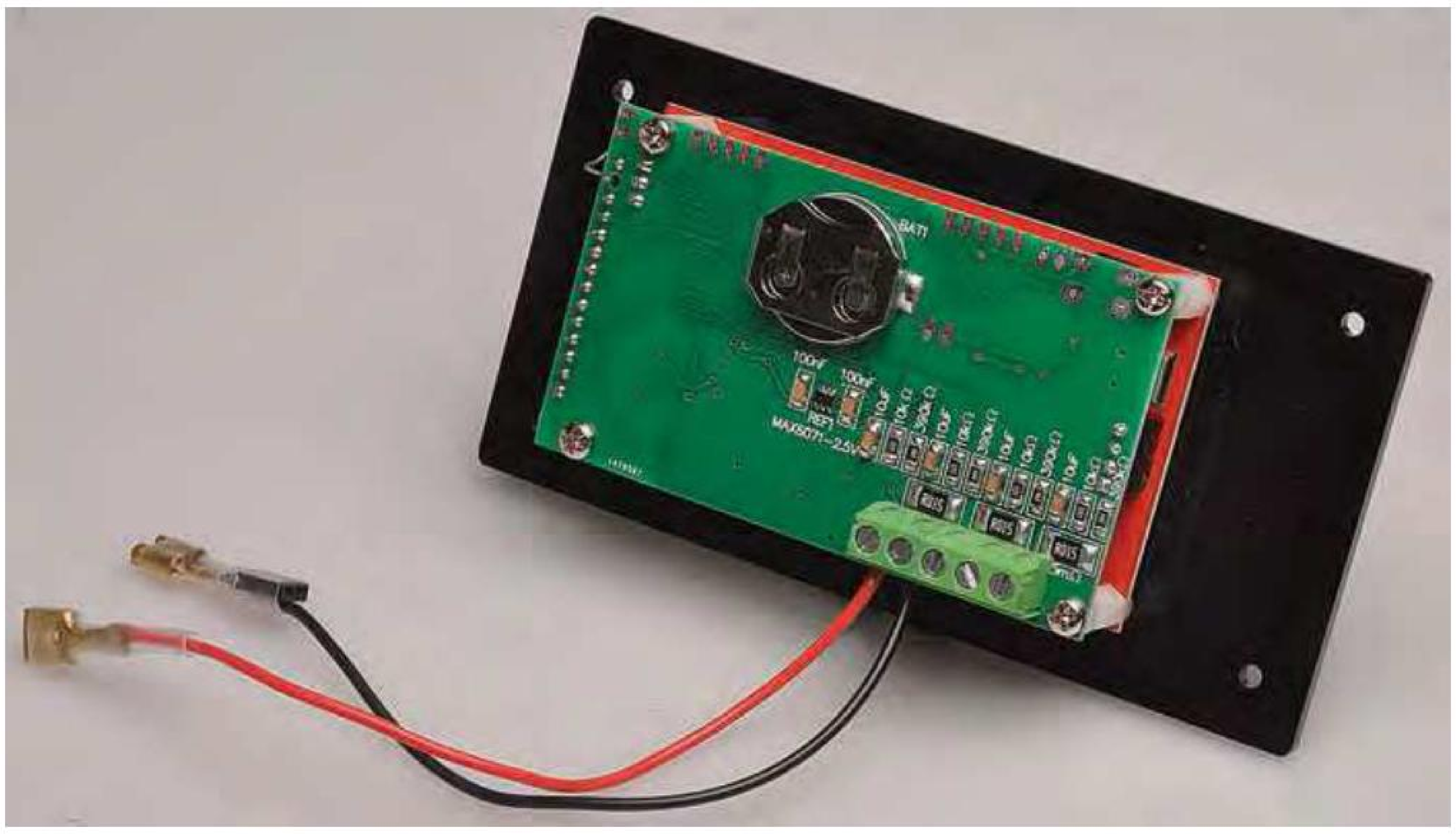
The initial values are set in the MMBasic program but can also be altered here, which you need to do if you are using shunts with values other than 15mΩ. The current calibration values are simply the inverse (reciprocal) of the shunt resistance in ohms, so the default 15mΩ shunts have a calibration factor of 66.67.

For I1, you will probably need to disconnect the battery to allow an ammeter to be connected in the *Battery Logger's* supply. When doing this, disconnect the USB cable and ensure that there is no load on any of the CON3A terminals.

The nominal value of the factor used for I1 is the inverse of the shunt resistor resistance (in ohms) divided by the op-amp circuit's gain. Consider that the measured shunt voltage would be the same as if the shunt resistance was multiplied by the gain. Therefore, the default value is the inverse of 0.1Ω, (ie, 1/0.1) which is 10, divided by 100 – in other words, 0.1

Mounting and completion

With everything calibrated and set up, you can mount and connect up the *Battery Logger*. Being a similar size and shape to the *V2 Micromite BackPack*, the *Battery Logger* can be fitted with the laser-cut acrylic front panel designed for UB3 Jiffy boxes. In this form, it can be mounted in a box. Or, you could opt to use the acrylic panel as a bezel to mount the *Battery Logger* in an equipment enclosure, with wires connecting internally and the touch panel being accessible from outside.



When fitted to the inside of an equipment enclosure, the important features are available for maintenance access, including cable terminations and the RTC backup battery.

To do this, separate the LCD and *Battery Logger* PCB by wiggling gently. Decide which side of the bezel you would like visible; we prefer the matte face, but it is reversible, so you can put the gloss side to the outside if you want.

Thread four of the M3 screws through the front of the bezel, place the washers over the threads, then follow with the LCD. The spacers provide clearance for the leads that protrude from the back of the headers.

Secure the M3 screws with the tapped spacers. Reconnect the *Battery Logger* PCB and secure it to the stack with the remaining M3 screws.

This complete assembly can now be attached, for example, to the front door of an equipment cupboard, using an M3 screw and nut in each corner to secure it. When the cabinet is opened, the battery connections can be accessed from the rear.

Protecting the back of the *Battery Logger* is easily done with the UB3 Jiffy box. The included screws might be too short if they need to screw through a panel, but the pillars will line up with the holes in the bezel.

In this case, all you need is a few holes in the side or back of the box to run the wires.

To complete the wiring, you can follow the three examples shown in Fig.6 (reproduced from last month). This shows options for use with internal and external shunts, including one possibility of sharing terminals on CON3A if you have more than three total loads plus charging sources.

Note that ideally, there should be a fuse on each wire out of CON3A (or in the high-current wiring leading to the shunts).

There should also be a fuse in the wire leading from the battery positive to CON3's positive terminal. This way, a fault in the *Battery Logger* or any of the connected loads cannot short out the battery.

The wiring will be specific to individual arrangements, so we can only offer general advice.

Conclusion

Like many of our projects, especially those written in MMBasic, we expect people will want to customise, tinker and perhaps improve the software.

We look forward to hearing what features readers would like to add, as we are already planning to supplement the *Battery Logger* with extra hardware in the future.

You will see that we haven't left many microcontroller pins unused, but we have broken out two pins to a header at the top right of the PCB. These are connected to the Micromite's I^2C pins, as we figured that would be a good way of expanding the device (they are already used for the real-time clock, but I^2C is a shared bus).

3.3V power and ground connections are also available at nearby CON2, while CON6 connects to the Micromite's second COM port (COM1), at pins 21 and 22.

That provides a dedicated communications channel that could be used to add more features.

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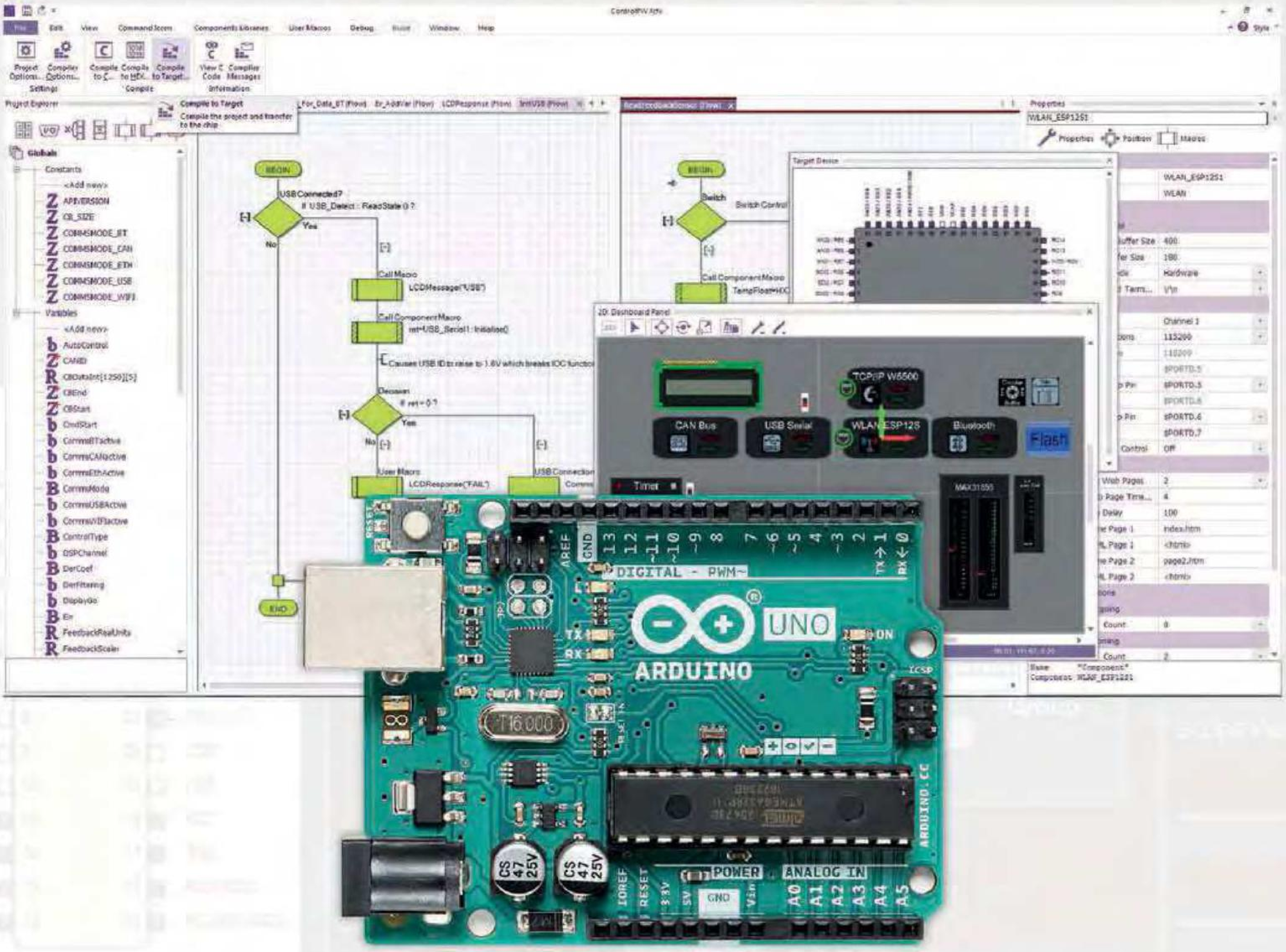
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Call Macro
LCDMessage("USB")
Call Component Macro
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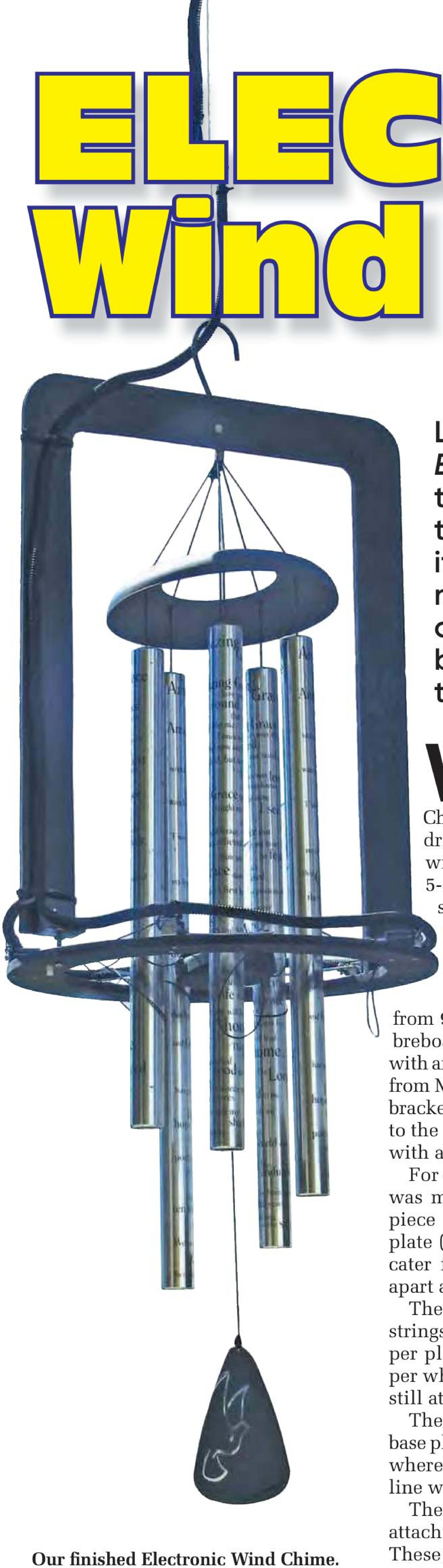
ELECTRONIC Wind Chimes

Part 2 – by John Clarke



Our finished Electronic Wind Chime. It's based on a commercial wind chime but ours works when there's no wind.

Last month, we described how our new *Electronic Wind Chime* worked, and how to build the electronics. Now we get to the tricky bit – modifying the wind chime itself so it can be driven by a series of solenoids. Fear not, because we have detailed instructions on how to accomplish this, and finish the build by putting it all together and setting up the electronics.

We modified a Carson Home Accents *Amazing Grace* 640mm Sonnet Wind Chime to incorporate the solenoid drivers (but you could experiment with any similar model). It is a 5-chime type with 31.5mm outside diameter tubes. The longest tube is 590mm and shortest at 450mm.

The solenoids are supported on a circular ring made from 9mm MDF (medium-density fibreboard). This ring is held in place with an inverted U-shaped piece made from MDF and a couple of right-angle brackets. The whole frame is attached to the wind chime's attachment hook with an M5 screw and nut.

For our prototype, the clapper plate was made using an 80mm diameter piece of 1mm aluminium sheet. The plate (shown in Fig.7) is designed to cater for the 5-chimes arranged 72° apart around the diameter.

The plate includes holes for the strings and a slot to allow the clapper plate to be placed over the clapper while its central support string is still attached.

The frame needs to be sized so the base plate can be positioned at a height where the solenoids and levers are inline with the top of the clapper plate.

There are two holes for the string attaching each solenoid to its chime. These need to be far enough apart so that the string does not touch the chime tube when pulled taut. This clapper plate can be glued in place, or held with a small self-tapping screw into the clapper after the string has been threaded.

The 100mm x 10mm rectangular solenoid levers are made from 1mm aluminium sheet; the two end holes are 3mm in diameter. Note that two holes are not centred, but placed close to one side, to give the best rotational movement when attached to the solenoid plunger.

The pivot point is a wood screw into the base plate. This should be long enough and screwed in sufficiently for the lever to sit horizontally, without being too tight to move.

The hole in the solenoid plunger was drilled to 2.5mm and then tapped for an M3 thread. That allows the lever to be secured at the fulcrum with just a 10mm-long M3 screw and no nut, with the screw acting as a bearing. Alternatively, you could drill 3mm diameter holes and secure them with machine screws and nuts.

The pivot hole is slightly elongated by about 1mm, to allow for the lever to move freely, allowing for length changes between the screws as it rotates with solenoid movement. A 6.3mm-long untapped spacer keeps the pivot raised and is secured with a 15mm-long No.9 countersunk wood screw into the base plate.

The solenoids are attached using screws into the solenoid housing. Our solenoids have M2.5-tapped mounting holes, so they are secured using M2.5 x 12mm screws. If no holes are provided, they can be glued in place instead.

Other options

The clapper plate and levers could be made from a material other than aluminium. The levers need to be thin enough to freely rotate within the solenoid plunger slot.

An easier material to work with is Presspahn or similar electrical insulation material (eg, Jaycar HG9985). This can be cut with scissors and a sharp craft knife.

The sizes given for the wooden frame and base plate are notional; these really depend on the wind chime you are using.

The circular ring base plate needs to have an inside hole large enough so the chime tubes can freely swing without hitting it.

The outer diameter needs to be sufficient for attaching the solenoids, with room for the pivot screws.

While we used MDF for the frame and base plate, you could make the frame from solid timber instead. The base plate does not need to be circular – it could be made in a polygonal shape instead.

The number of straight sides could equal the number of chimes; for our 5-tube chime, that would be a pentagon.

Note that once the solenoids and levers are in place, there is not necessarily a convenient point to attach the frame to the chime where it will not interfere with at least one lever. This is especially true with an odd number of solenoids.

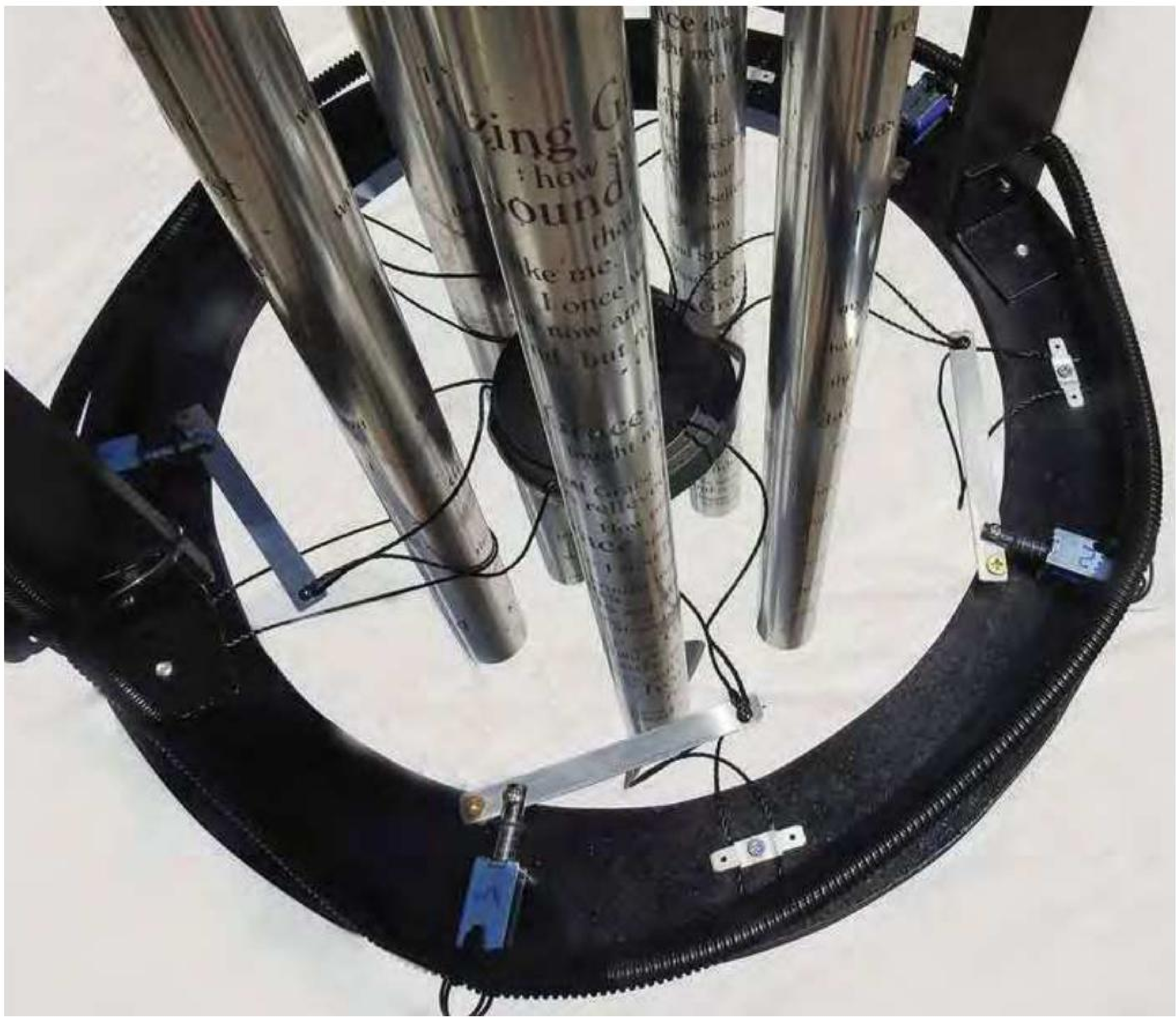
However, there should be one side of the frame that can be directly attached to the base plate. The other leg can be supported with a bracket that is raised above the base plate using a screw and nuts to clear lever movement (see our photos for details).

Alignment

The frame needs to be aligned correctly to the base plate. This is so that when the frame is held by the wind chime attachment hook, the solenoid levers and strings are positioned correctly, so that the clapper is pulled along the radial line from the centre of the clapper to the centre of the chime tube for each solenoid.

If it is not possible to get this alignment without the frame interfering with the solenoid drivers, the positioner at the top of the wind chime may need to be rotated.

Rotating the chime positioner will effectively twist up the strings at the attachment hook, so it will not stay in this rotated position. The solution is to tie the chime positioner against the side of the frame. A small hole in the side of the chime positioner and another in the frame will allow for a short length of string or stiff wire to hold the chime positioner in its rotated position.



A close-up of the 'business' end of the electronic wind chimes, showing how the solenoids are placed around the ring. The solenoids do not strike the chime tubes; rather, they pull the clapper towards the tube which makes the sound. In this photo, some of the catch strings and pull strings were removed from the closest chime tubes for clarity.

Stringing the chime

The pull strings must normally be loose. These pull the clapper toward the chime near the end of the lever travel.

The loose stringing is for two reasons: first, the solenoid pulling force is not particularly strong at the beginning of its movement from its resting position, and it is greatest when it fully pulls in the plunger. The looseness allows the solenoid to 'build up strength' before it starts moving the clapper.

The second reason is so that when one solenoid pulls the clapper in its direction, it is not affected by the strings becoming taut on the opposite side. The looseness needs to be a compromise between being tight enough to be able to pull the clapper against the chime, and loose enough not to affect the opposing solenoid pulls.

The strings pass through the clapper holes and back to the lever, and are secured by passing the string through the lever hole. An M3 x 6mm screw and M3 nut can be used to secure the string in the hole. This more easily allows fine adjustments compared to tying a knot.

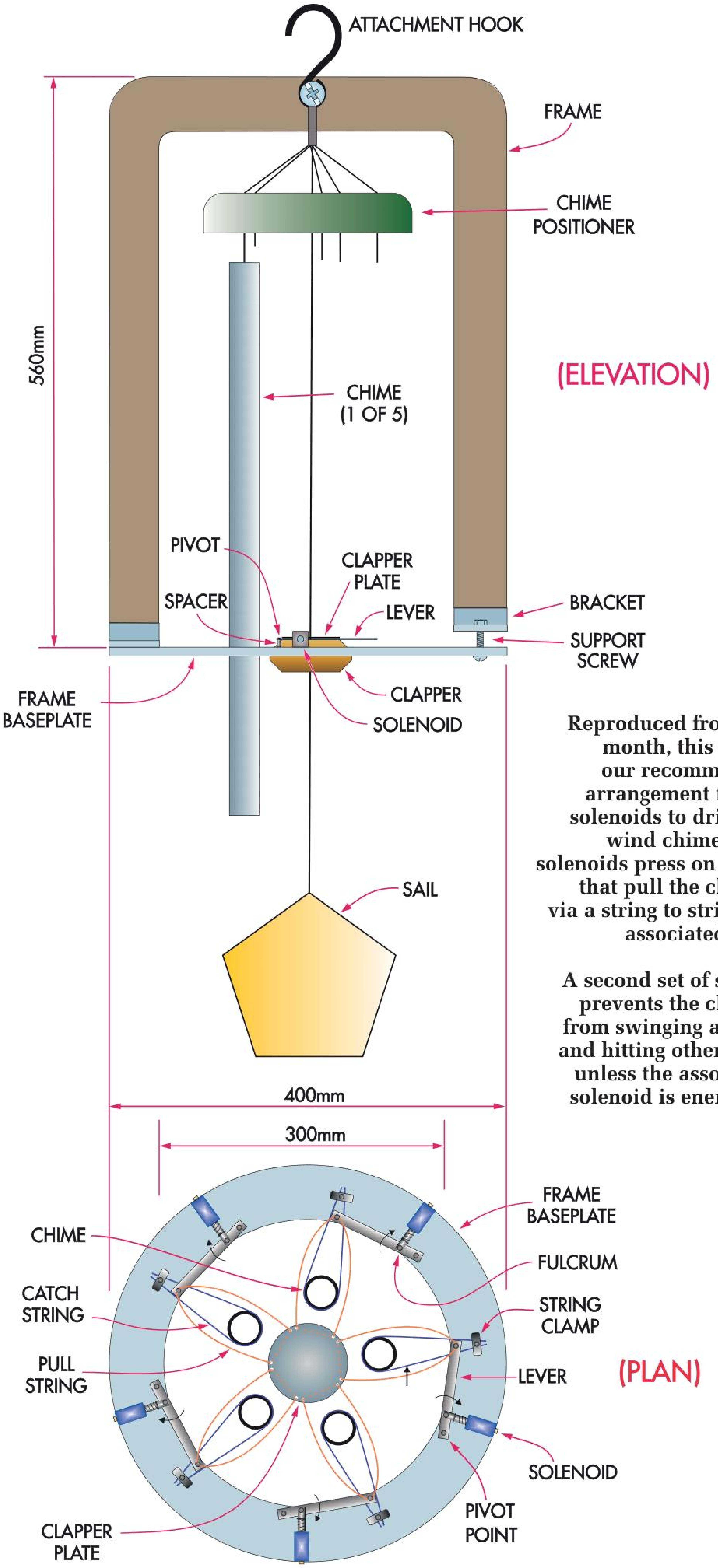
A refinement to the design is to include catch strings. These catch and hold the chime tube, preventing it from swinging back to re-strike the clapper after striking the chime tube. Their lengths are such that they are loose when the tube sits in its usual position, but tight enough to prevent it swinging back and hitting the clapper. The string ends are held to the base plate by clamps.

We used polyester string, which becomes unravelled if cut with scissors or a knife. Instead, the string was cut to lengths with a hot soldering iron tip that both cut and welded the string ends to prevent fraying. We don't recommend you use your primary, high-quality iron to do this, though! You can also cut the string and then use a lighter to weld the ends before they unravel.

Wiring

Use sufficient gauge wire (eg. 19 x 0.1mm strands) or similar for the larger solenoids, so that voltage drops will not affect solenoid operation. If the wire cross-sectional area is too small, then the solenoids may not work with longer wire runs back to the main PCB.

We used a 7mm tube loom to hold the wires in place and keep the



Reproduced from last month, this shows our recommended arrangement for the solenoids to drive the wind chimes. The solenoids press on levers that pull the clapper via a string to strike the associated tube.

A second set of strings prevents the clapper from swinging around and hitting other tubes unless the associated solenoid is energised.

appearance neat. The +12V wires to each solenoid are connected together and brought back to terminate into the positive terminal of CON1 or CON6. The second wire of each solenoid connects between the solenoid outputs at CON1-CON6 and the negative terminal of the solenoid.

After soldering the solenoid wires to the extension wires, insulate the joints using electrical tape or heatshrink tubing. When finished, we attached the wire loom to the top of each solenoid using cable ties so that it won't move around.

The main enclosure housing the PCB can be located on a timber beam above the wind chime attachment, or further away out of sight.

Setting up

There are several options that need to be set in the *Electronic Wind Chime* controller before you can use it.

LDR adjustments

If you prefer not to have the Wind Chime paused during darkness, place a shunt on JP2. In this case, the LDR does not need to be installed.

But if you do want it to stop at night, remove the shorting block from JP2 and switch on the power. LED2 should light, indicating that there is power. VR2 can then be adjusted to set the light threshold that switches the *Electronic Wind Chime* on or off.

With the LDR in normal shaded daylight, place your finger over the LDR and adjust VR2 so that LED1 (the status LED) starts flashing at 2Hz. This indicates that playback is paused.

Lifting your finger from the LDR should result in that LED switching off. The more clockwise VR2 is adjusted, the darker the light needs to be to pause playback.

Calibration

The LDR is ignored during calibration and recording. It is only used during playback, and only if JP2 is open. This is so that calibration and recording are not interrupted by a change in light level.

Each solenoid can be independently calibrated for the drive voltage (using PWM) and for the on-period. These two parameters are adjusted using VR1 and JP1, as described below.

The 500Hz PWM duty cycle can be adjusted between about 5% to 100% in approximately 0.75% steps. This varies the average voltage between 600mV and 12V in about 90mV steps. The on-period can be set to between 2ms and 254ms in approximately 2ms steps. Initially, all solenoids receive the full 12V drive voltage (100% duty cycle) for a duration of 254ms.

To initiate calibration, press and hold the control switch (S13) at power-up. The status LED (LED1) lights for 200ms then flashes off for 200ms and then on again. This indicates that calibration has been activated.

Press a solenoid switch (S1-S12) to select which solenoid is to be calibrated. The status LED extinguishes, and the solenoid drive parameters are now ready to be adjusted for the chosen solenoid. When JP1 is shorted, the PWM duty cycle can be adjusted with VR1, and when JP1 is open, the drive duration (on-period) is adjusted with VR1.

Once you have set JP1 and adjusted VR1 for the setting you want to make, press the control switch (S13) to temporarily store that particular parameter. This will also drive the relevant solenoid, so you can check whether the setting is correct. If not, readjust VR1 and press S13 again.

If you want another solenoid to have the same parameter, the switch (S1-S12) for that solenoid can be pressed, and the control switch (S13) pressed again to store the current parameter value for that solenoid.

We have also provided a means of monitoring the current VR1 setting using a multimeter measuring the voltage between TP1 and TP GND. That makes it easier to replicate suitable values for other solenoids.

The status LED (LED1) lights each time you press the control switch for the duration of the solenoid drive. Lower PWM duty cycles will cause the solenoid to move more slowly. Adjust the solenoid on-period to allow sufficient time for the solenoid to pull the clapper against the chime tube, but short enough for it to pull away before the chime tube returns after being struck.

As mentioned, the solenoid parameters are initially only temporarily stored. The values will be lost when the power goes off unless they are stored in Flash memory. This is also done with the control switch.

While pressing the control switch for a short period tests the solenoid drive, a longer press (one second or more) will store all solenoid parameter values into the permanent Flash memory. LED1 will light again if the switch is held for one second or more, to indicate that the values have been written to Flash.

To exit the calibration mode, switch off power. When power is switched on again, without S13 being pressed, the *Wind Chime Player* starts up in playback mode.

You can return to the calibration mode again by repeating the above procedure, to re-adjust those parameters. Only the parameters for the selected solenoid or solenoids will be changed. Previously stored parameters will remain unchanged unless new parameters are stored for that solenoid.

Recording a sequence

To make a recording, press the control switch, S13, after power-up. The status LED, LED1, lights and stays lit, indicating that recording has begun.

Table 1 – switch actions at power-up

S1	Randomness off
S2	Randomness on
S3	Delay varies in 128 steps between 10s and 1280s (21:20)
S4	Delay varies in 64 steps between 10s and 640s (10:40)
S5	Delay varies in 32 steps between 10s and 320s (5:20)
S6	Delay varies in 16 steps between 10s and 160s (2:40)
S7	Delay varies in eight steps between 10s and 80s (1:20)
S8	Delay varies in four steps between 10s and 40s (0:40)
S9	Delay multiplier varies randomly between one and five times actual
S10	Delay multiplier varies randomly between one and three times actual
S11	Delay multiplier varies randomly between one and two times actual
S12	Delay multiplier varies randomly between one and 1.5 times actual

You can then press the individual solenoid switches to activate the solenoids, and it records the sequence you provide and the pauses in between. You can close one solenoid at a time.

The PCB includes white screen-printed squares above each switch so you can write the perceived note using a fine marker pen. We say the 'perceived note' because the sound from the chime comprises many overtones, which may affect the apparent frequency. It may also appear to shift in frequency after initially struck.

The perceived note cannot be easily measured with a spectrum analyser. Probably the easiest method is to use a guitar tuner or similar device and adjust it until its apparent frequency matches the chime, then look at what note you have selected.

For more information on the perception of sounds from wind chimes, see: **https://bit.ly/pe-mar22-ewc1** and **www.sarahtulga.com/Glock.htm**

During recording, you can play out a tune if you are musically inclined, or just some nice sounds that appeal to you. Short gaps between chime strikes can be waited out in real time before driving a solenoid for another chime. Longer intervals may become tedious to wait out in real time, but we have a solution to that.

Time warp

By pressing the control switch for longer than one second, that period stored for the current pause is multiplied by ten. The status LED flashes at 1Hz to meter out the time (one flash is one second of real time, but ten seconds of

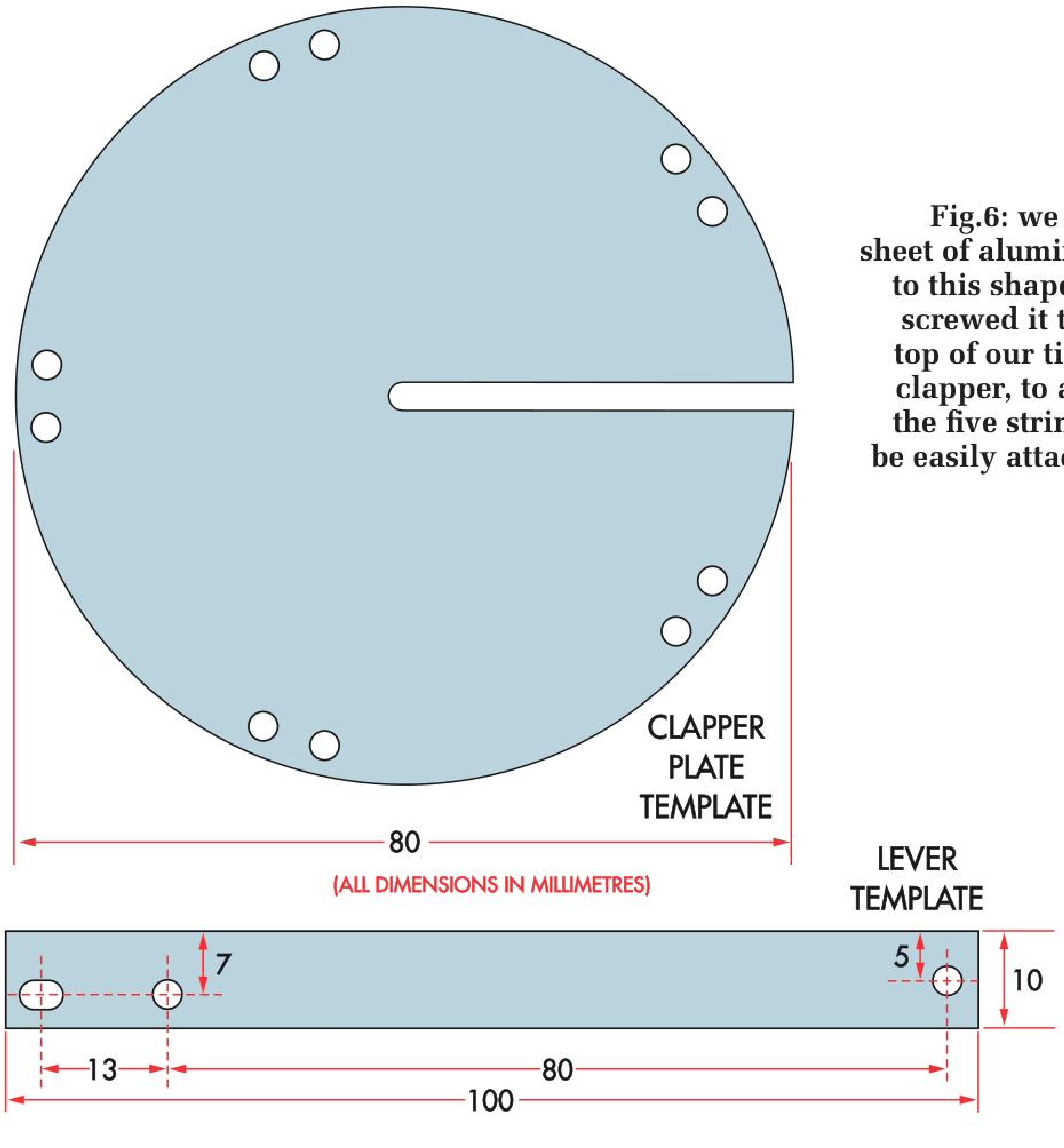


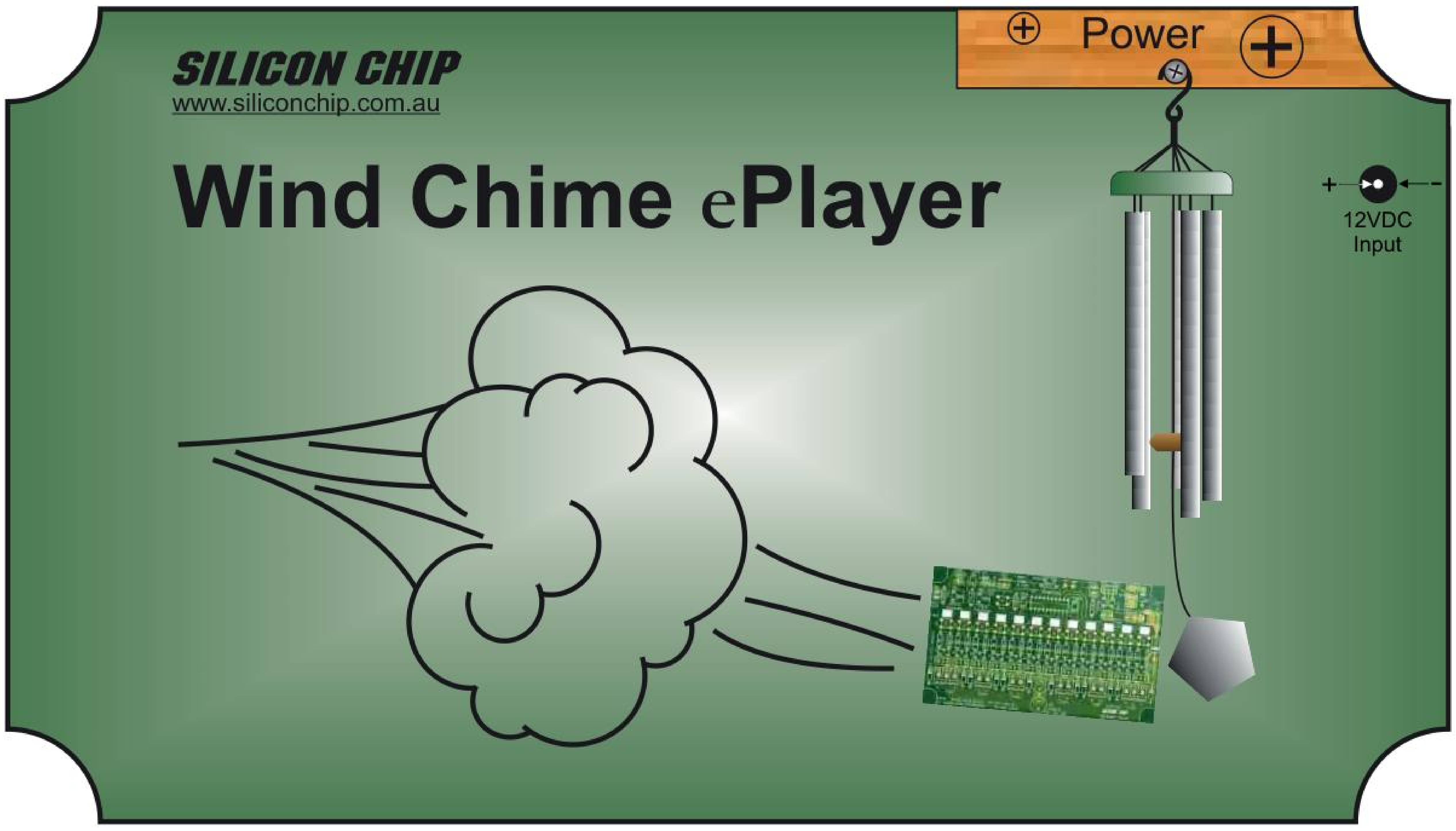
Fig.6: we cut a sheet of aluminium to this shape and screwed it to the top of our timber clapper, to allow the five strings to be easily attached.

delay). Be careful when pressing S13, since if you press it for less than one second, instead of activating the time warp, it will end the recording.

After a short press of the control switch, the entered sequence will be written to Flash memory, and it will return to playback mode. If no solenoid switches were pressed while in record mode, the previous recording will remain in memory.

Playback

At power-up, the *Electronic Wind Chime* starts in playback mode. This plays back the recorded sequence, repeating it in a continuous loop. The initial setting is for no randomness in the delay periods between chime strikes – in other words, it faithfully reproduces your recorded sequence.



Two front panels designs are provided – one has provision for through-panel switch and LED whereas the other panel doesn't. These can both be downloaded from the March 2022 page of the PE website.

Adding randomness

As mentioned earlier, you can add randomness to the delay between chime strikes. This is selected by pressing switch S2 while powering up. Wait for the status LED (LED1) to flash after about one second before releasing S2, indicating that the randomness feature has been enabled.

The setting is stored in permanent memory. If you want to switch the randomness off, hold switch S1 at power up and wait for the status LED to light before releasing it.

There are two randomness parameters that can be adjusted. One is the rate; how often the random value changes. This can be set to six different values. The randomness changes at an interval between ten seconds and the maximum value selected. The options are 1280s (21:20), 640s (10:40), 320s (5:20), 160s (2:40), 80s (1:20) and 40s (0:40).

These options are selected by holding one of switches S3, S4, S5, S6, S7 and S8 at power-up – see Table 1.

You can also change how much variation you want in the delays. There are four options, selected by holding one of switches S9, S10, S11 or S12 down at power-up.

The delay multiplier varies randomly between one and the maximum value selected. S9 selects a range of 1-5 times, S10 1-3 times, S11 1-2 times and S12 1-1.5 times variation (also see Table 1).

If you haven't already pressed any of these switches at power-up, then the initial setting is with randomness off. If randomness is switched on (using S2), then the 10s to 1280s (21:20) randomness change rate is selected, along with the 1-5 times delay range.

Note that you can press and hold more than one switch at power up to select more than one option at the one time.

For example, you could switch randomness on (with S2), set the randomness change rate at up to 320s with S5, and the randomness variation to between one and three times with S10, all at the same time.

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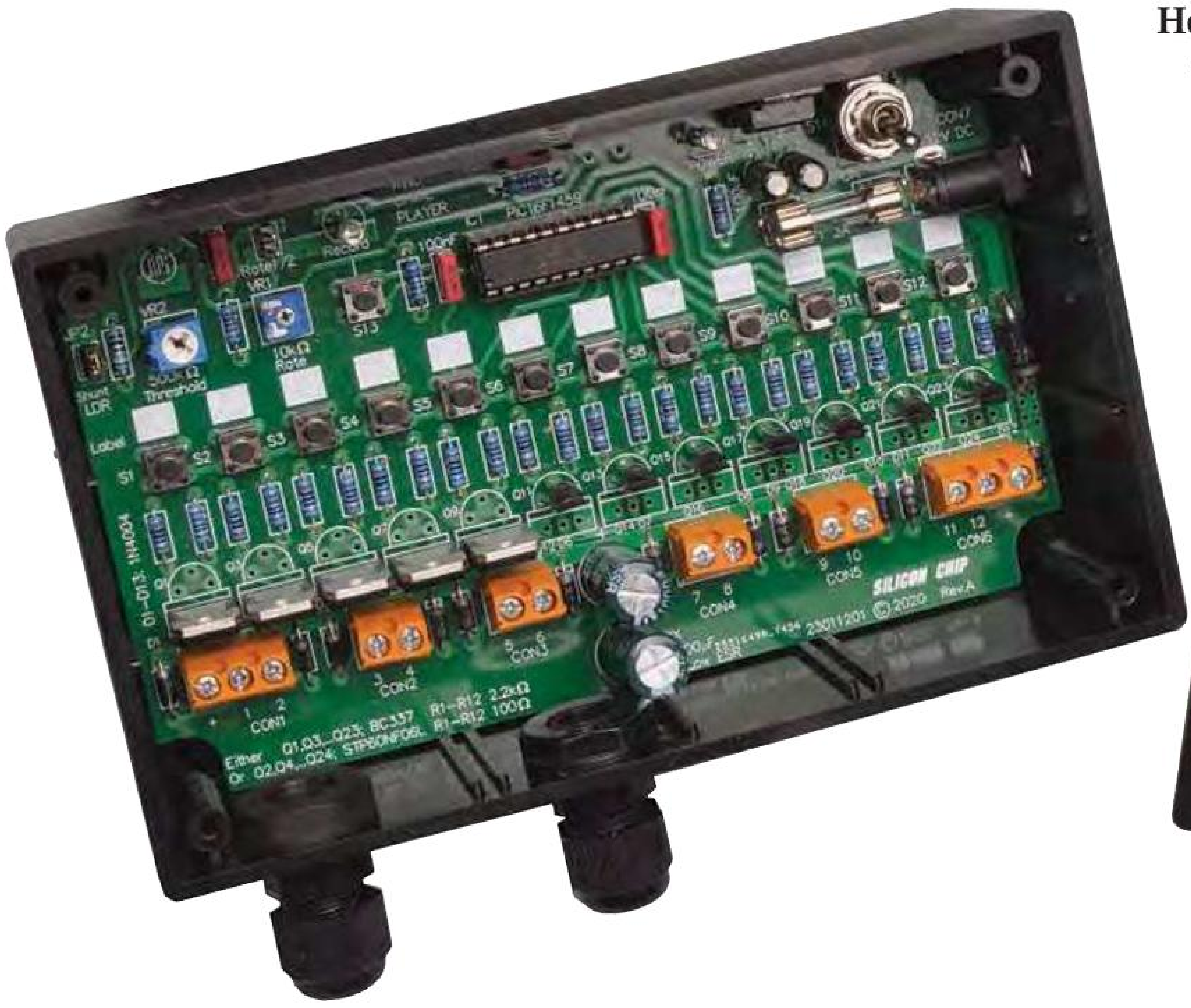

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Wind Chime ePlayer
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Input

Here's the Electronic Wind Chime PCB placed inside the case, albeit without any cables connected, while at right the front panel and label are placed.

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Using Cheap Asian Electronic Modules **By Jim Rowe**

Geekcreit LCR-T4 Mini Digital Multi-Tester

MTester
Testing...
[Vbat=9.15V]
HW-308

It's hard to believe, but you can get a compact digital tester which will identify, check and analyse bipolar transistors, JFETs, MOSFETs, diodes, LEDs, thyristors, resistors, capacitors and inductors for less than most joints charge for lunch these days! The Geekcreit LCR-T4 does all of the above and will cost you under a tenner, or a little more if you want it in a case rather than just a bare board.

When I first spotted the Geekcreit LCR-T4, advertised on the Banggood website, I thought it was too good to be true.

It was described as a '128x64 LCD Graphical Transistor Tester Resistance Capacitance ESR SCR Meter', priced at only about) £5.60 plus £2 for airmail – a total of just £7.60! I was curious and so decided to order a couple straight away.

When they finally arrived (about five weeks later), unfortunately, I found that one of the two LCR-T4s was damaged in transit. There was a chunk of glass broken off the top right of its LCD panel, and the bottom half of the screen wasn't working. Luckily, the other unit worked fine, so I was able to proceed with the review.

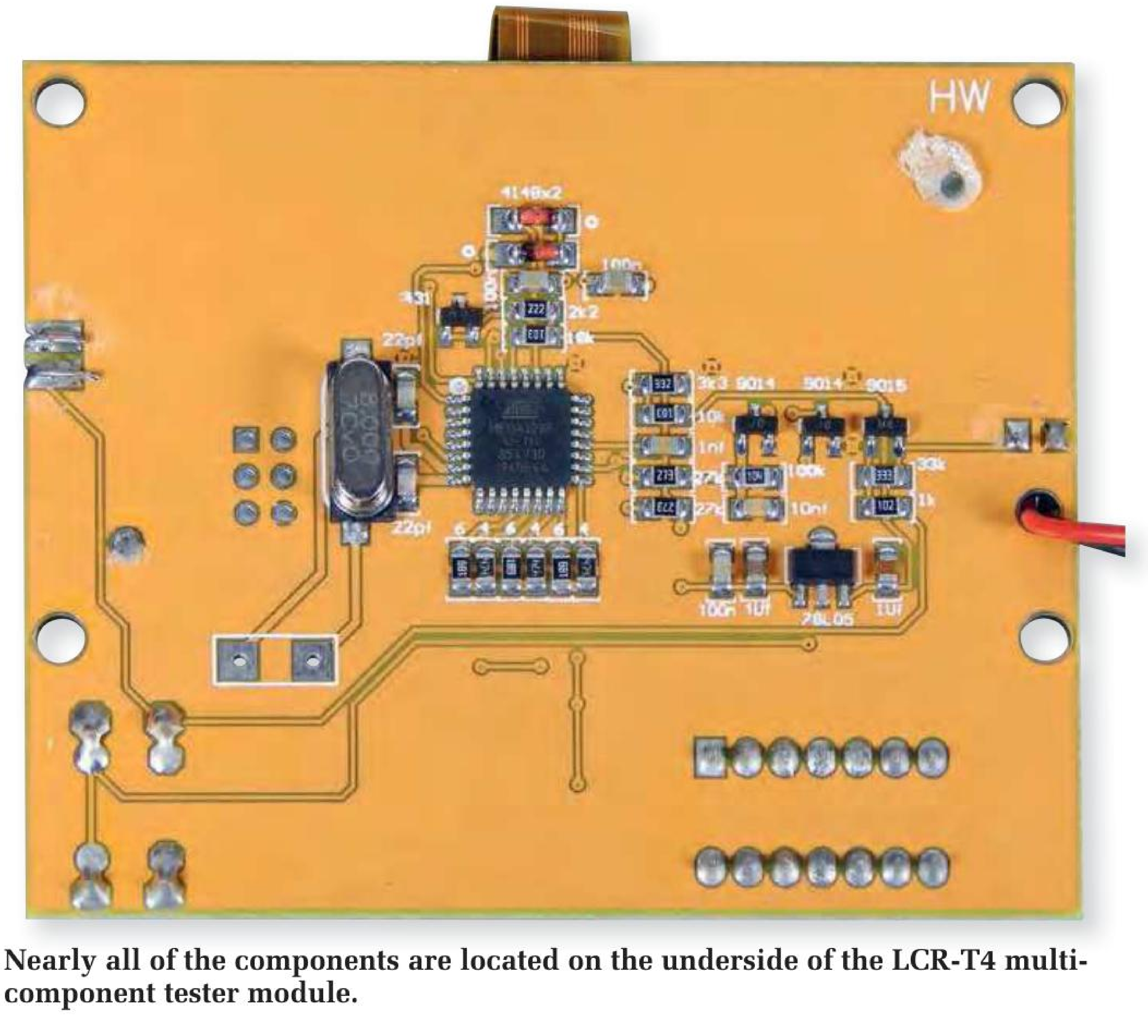
I then discovered that it is also available with an assemble-it-yourself clear plastic shell, for £12.75 plus £2.50 air parcel shipping. I ordered one of those as well, based on my positive impression of the 'naked' version, but it hasn't arrived yet.

Components and construction

The multi-tester is built on a single PCB measuring 73 x 60mm. The only components on the front are the 128x64-pixel LCD panel with green LED backlighting, a 14-pin ZIF socket used to connect to the device being tested, and a pushbutton switch to initiate testing.

The rest of the tester's components are on the rear of the PCB, including an ATmega328 MCU (microcontroller unit), an 8MHz crystal, a 78L05 regulator, a TL431AN 2.5V voltage reference, three small SOT-23 bipolar transistors, two 1N4148 diodes and a handful of passive components.

The tester uses a 14-pin ZIF socket because it provides a range of options



Nearly all of the components are located on the underside of the LCR-T4 multi-component tester module.

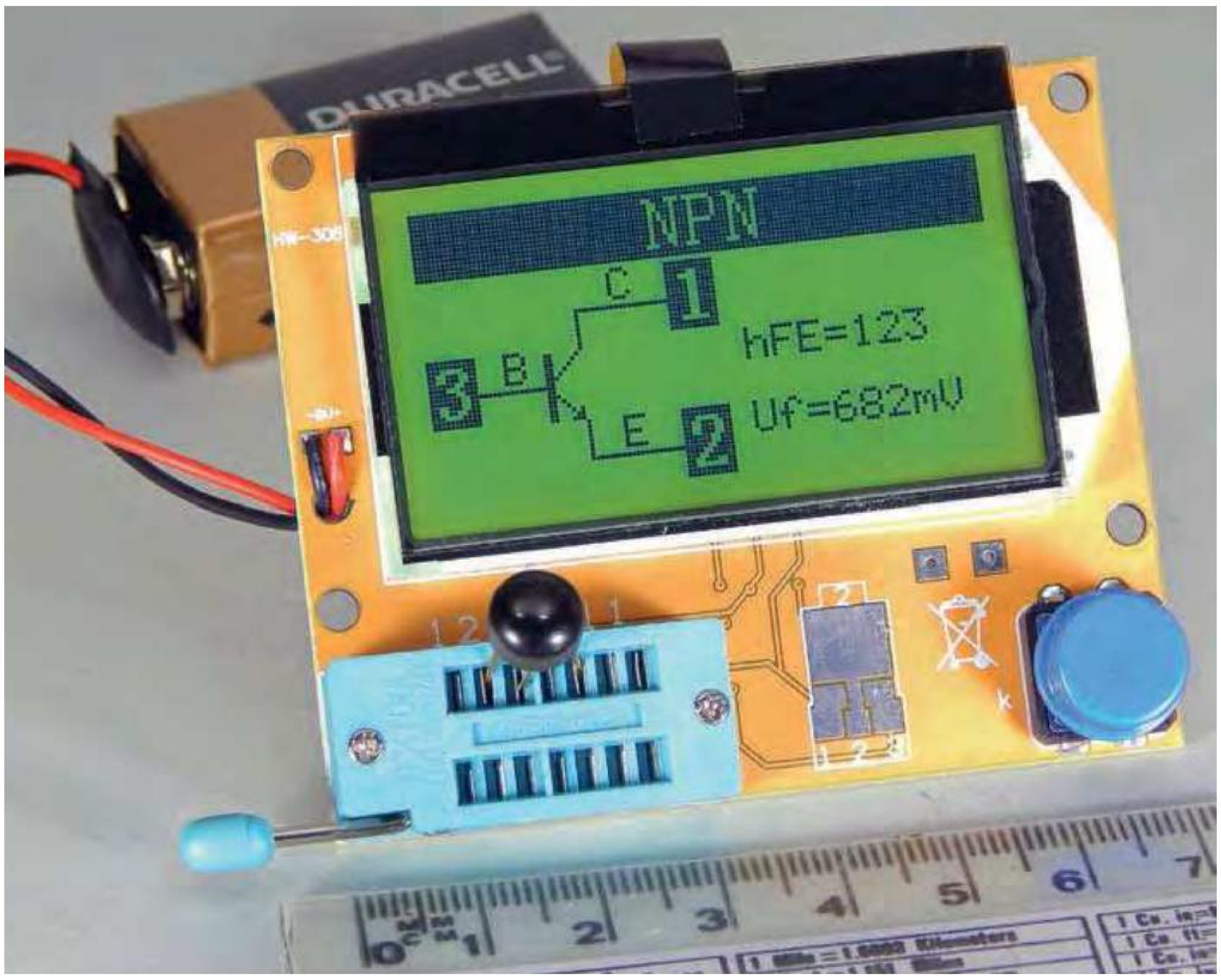
when it comes to components with different pin configurations and spacing. Although there are only three inputs (logically labelled 1, 2 and 3), the two rows of seven pin positions on the ZIF socket are connected in this order: 1-2-3-1-1-1-1 (left to right). This gives you quite a bit of flexibility for connecting different devices.

There's also a small 'D-PAK' type array of plated copper pads for receiving SMD components, just to the right of the ZIF socket. Presumably, SMD devices to be tested have to be pressed against the PCB to make decent contact during testing.

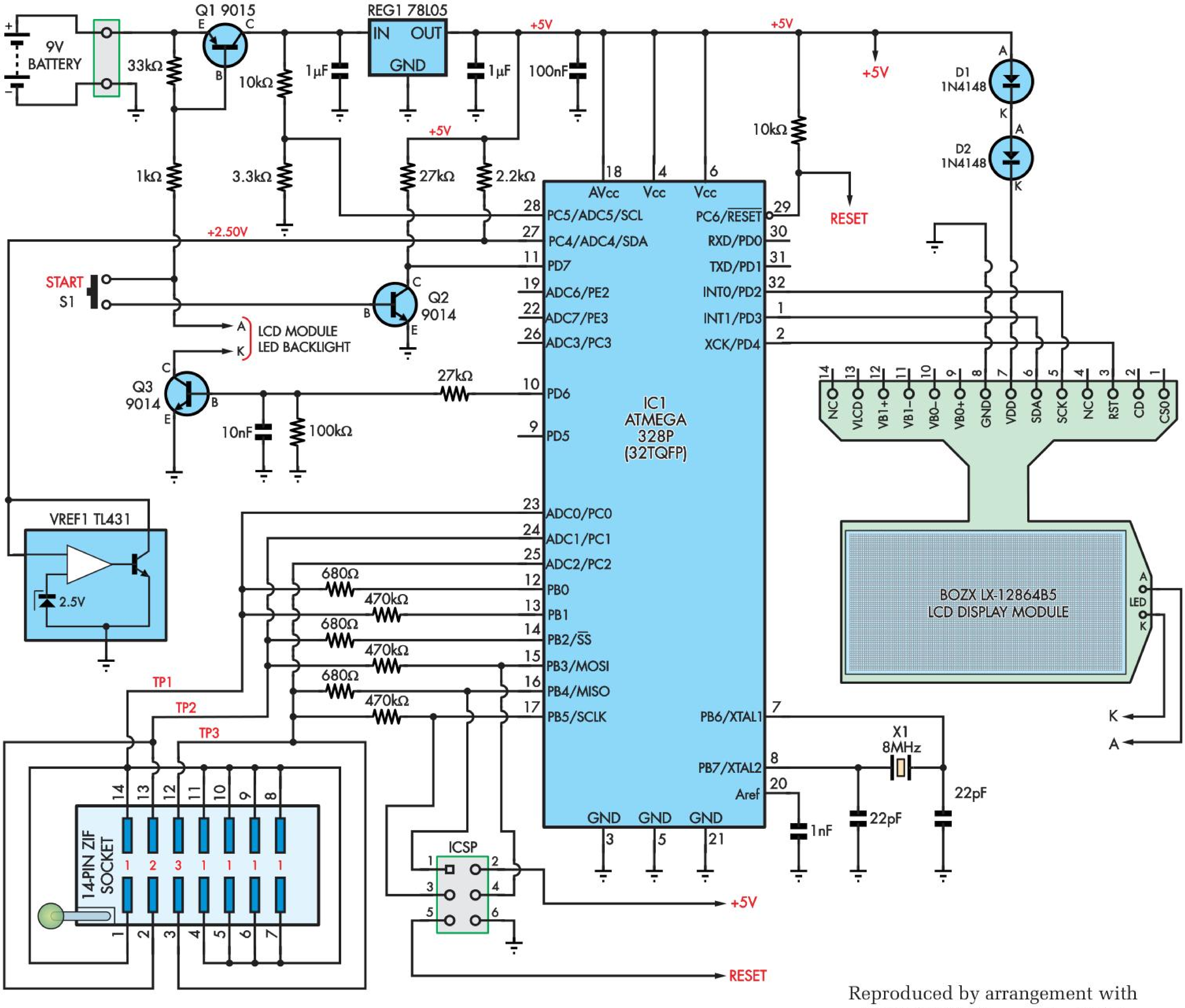
The complete tester is powered by a standard 9V battery via a battery clip lead.

It's straightforward to use

What, no power switch? Well, the pushbutton switch on the front of the PCB does everything. If it hasn't been pressed, the tester is in 'sleep' mode with its current drain from the battery less than 20nA.


DURACELL
NPN
C 1
3 B
E 2
hFE=123
Uf=682mV

Here's the LCR-T4 testing an NPN transistor (an AY1103 which was made by Fairchild Australia).


9V BATTERY
33kΩ
Q1 9015
E C B
10kΩ
1kΩ
3.3kΩ
REG1 78L05
IN OUT GND
1µF
1µF
100nF
+5V
+5V
27kΩ
2.2kΩ
+2.50V
START S1
Q2 9014
LCD MODULE LED BACKLIGHT
A K
Q3 9014
27kΩ
10nF
100kΩ
VREF1 TL431
2.5V
680Ω
470kΩ
680Ω
470kΩ
680Ω
470kΩ
TP1
TP2
TP3
14-PIN ZIF SOCKET
1 2 3 1 1 1 1
IC1 ATMEGA 328P (32TQFP)
AVcc Vcc Vcc
PC5/ADC5/SCL
PC4/ADC4/SDA
PD7
ADC6/PE2
ADC7/PE3
ADC3/PC3
PD6
PD5
ADC0/PC0
ADC1/PC1
ADC2/PC2
PB0
PB1
PB2/SS
PB3/MOSI
PB4/MISO
PB5/SCLK
PC6/RESET
RXD/PD0
TXD/PD1
INT0/PD2
INT1/PD3
XCK/PD4
PB6/XTAL1
PB7/XTAL2
Aref
GND GND GND
ICSP
RESET
10kΩ
D1 1N4148
D2 1N4148
NCO VLCD VB1+ VB1– VB0– VB0+ GND VDD SDA SCK NCO RST CD CS0
BOZX LX-12864B5 LCD DISPLAY MODULE
LED A K
X1 8MHz
22pF
22pF
1nF

Geekcreit LCR-T4 Mini Multitester

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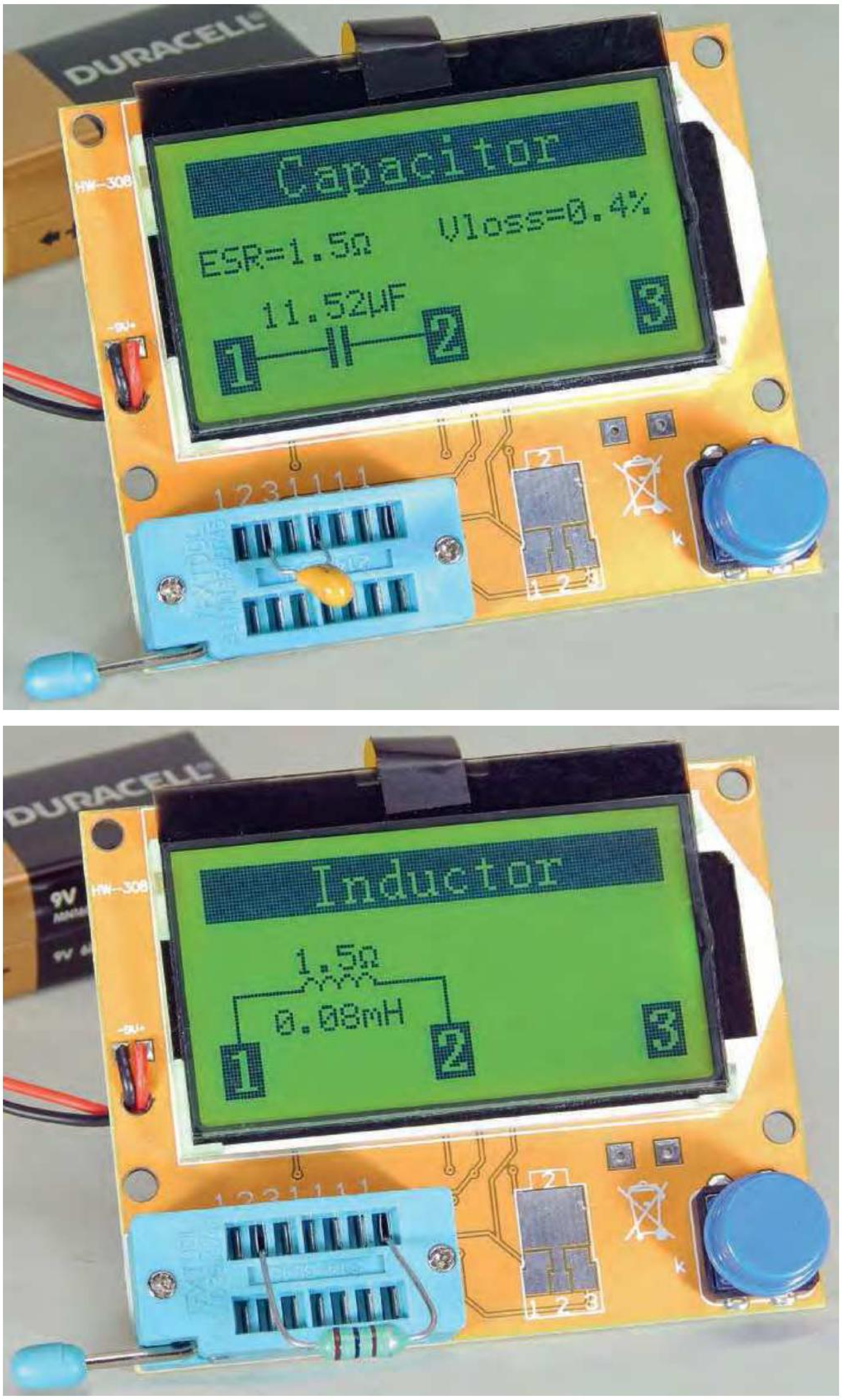

The LCR-T4 can measure capacitors from 25pF to 0.1F with an accuracy of about 2%, and inductors from 10µH to 20H with a worst case accuracy of 30%.

When you do press the button, the tester springs to life. The LCD backlight immediately turns on, and the screen displays the message 'Testing ...', together with an indication of the battery voltage, like '[Vbat = 9.15V]'.

Then the tester starts checking to see if anything is connected to the inputs. If it doesn't find anything, it displays a large question mark, plus the message 'No, unknown or damaged part'.

But if it does find an NPN or PNP bipolar transistor, a JFET, a MOSFET, a diode, an SCR, a Triac, a resistor, a capacitor or an inductor connected to the inputs, it works out the component's configuration and shows it, together with some basic measurement data. And the test results are displayed for about 10-30 seconds after you press the button, before the tester turns itself off again automatically.

The tester's current drain during the actual testing is less than 25mA, so if you power it from a 9V alkaline battery, it should last for quite a while.

No user guide

Unsurprisingly, the LCR-T4 came without any user guide, or even any link to a source of such a guide. However, when I did a bit of Googling, I came across this link to a very detailed and informative 'white paper' as a PDF at: **https://bit.ly/pe-mar23-lcr**

It's quite big (127 pages), and not that easy to read since it appears to be translated from German. It was originally written by Karl-Heinz Kubbeler (**kh_kuebbeler@web.de**), and in it, I was able to find some information on both the origin of the LCR-T4, how it works and how to use it.

The original design, called the 'AVR Transistortester' was first published by Markus Frejek in 2011, in the German publication *Embedded Projects Journal*. After that, Mr Frejek refined the design and added various enhancements. It wasn't long before quite a few 'clones' of his tester began to emerge from China.

At first, these variations-on-the-theme sported 16x2 LCD character displays and used an ATmega8 MCU. But soon, other versions started to appear with 128x64 pixel graphic LCDs and an ATmega328, ATmega1280 or even ATmega2560 MCU (with much more program memory). And so the Frejek transistor tester snowball kept on growing...

Many variants

Nowadays, there seem to be a lot of different variations on the original Frejek design, and you'll find them on offer by many different vendors online. As well as the Geekcreit LCR-T4, there is the Fish8840, the WEI_M8, the DROK, the FD_it TC-T7-H (also known as the DANIU LCR-TC1), the LTDZ_M328_7735 and the GM328A.

Some of these come in a plastic case, others with an assemble-it-yourself case or just as a naked PCB module like the LCR-T4. Others have extra features like a built-in PWM square wave generator with an output up to 2MHz and adjustable duty cycle and/or a frequency meter with a range up to 1MHz.

But they all seem to have the same basic features offered by the Geekcreit LCR-T4, with prices moving upwards according to the addition of those extra features.

How it works

As you've probably guessed by now, the LCR-T4 and the other clones of Mr Frejek's tester work in much the same way. Given the relatively small number of external components, clearly, most of the hard work is done by the firmware running on the microcontroller.

The TL431AN voltage reference allows the MCU's analogue-to-digital converter (ADC) to measure device voltages accurately.

At the same time, the three small bipolar transistors enable the MCU to wake itself up and turn on the LCD backlighting as soon as the 'GO' button is pressed, then turn off the power and go back to sleep after the testing has finished.

I think you'll agree that it's quite nifty. Hats off to Mr Frejek for his innovative thinking!

Measurement features

Now let's look at the measurement data displayed for the different devices the LCR-T4 can test.

1. Silicon, germanium or schottky diodes

It displays the anode and cathode connections (ie, the orientation), the forward voltage drop (Uf), and the junction capacitance (in pF) when the diode is reverse-biased. LEDs can be tested as well, with the tester displaying them as a diode with a higher-than-usual forward voltage.

2. NPN and PNP bipolar transistors

It shows the pin connections for the base, emitter and collector (B, E and C), the current gain, hFE (also known as Beta) and a voltage reading 'Uf', which appears to be the base-emitter voltage during low-current conduction.

When I checked several silicon BJTs, the Uf readings were always over 600mV, while for germanium BJTs, the Uf readings were generally below 200mV.

3. Darlington transistors

It's claimed to be able to test Darlington transistors, giving the same parameters as for regular BJTs. But when I tried testing a few Darlingtons, it didn't seem to recognise that they were Darlingtons and gave relatively low hFE readings. So I would not recommend testing Darlingtons with this device.

4. JFETs and depletion mode MOSFETs

It displays the pin connections for the gate, source and drain, plus the orientation of a protective diode if it finds one present. It also shows the gate-source threshold voltage (usually written Vgs, but labelled 'Vt' here) and the gate-source capacitance, Cgs.

5. Enhancement-mode MOSFETs

For these far more common MOSFETs, it again shows the G-D-S pin connections plus the orientation of a protective diode if it finds one. It also indicates the gate-source threshold voltage ('Vt') and the gate-source capacitance, Cgs.

6. SCRs and Triacs

It just identifies them and shows their pin connections.

7. Resistors

It measures and displays the resistance. The rated measurement range is from 0.1Ω to 50MΩ, and when I checked a fair number of reference resistors, it gave readings better than ±2% for values between 50Ω and 2MΩ.

Below 50Ω, the error gradually rose to +7% at 10Ω, while above 2MΩ, it gradually increased to –4.4% at 50MΩ. That isn't wonderful, but not bad for a low-cost tester making two-terminal measurements.

8. Capacitors

It measures and displays the capacitance. The rated measurement range is from 25pF to 100,000µF, although for capacitors with very high values, the measurement time can extend beyond one minute.

For capacitance values 1µF and above, the tester also displays the capacitor's ESR (equivalent series resistance). I checked quite a few reference capacitors with values between 25pF and 10µF, and obtained readings accurate to within ±2% over this range. Not bad for a low-cost tester.

9. Inductors

It measures and displays both the inductance and resistance. The rated measurement range is from 0.01mH (10µH) to 20H. I checked 14 different reference inductor values from 27µH up to 1.09H, and obtained readings that were within ±6% for values of 1mH and above, but rising to ±30% for lower values. The series resistance readings given were all quite sensible.

The bottom line

After testing the LCR-T4 mini multitester fairly thoroughly, I think it's a 'little blooming wonder' and excellent value for money.

I have a few small gripes, though. One is the lack of any user guide, forcing you to search the web and digest Mr Kubbeler's big 'white paper'. Then there's that lack of clarification for the exact significance of the Uf reading for bipolar transistors.

And thirdly, in its naked form, the tester is really quite fragile – which explains why one of the two units I ordered was damaged in transit. So I'm looking forward to receiving the matching assemble-it-yourself plastic case that I ordered recently.

One last comment: if you compare the LCR-T4 with my *Semtest Discrete Semiconductor Test Set* design (*PE*, February to April 2013), you will see that there are huge differences between the two in complexity and cost. The Semtest offers more tests, but Mr Frejek's design is clearly very elegant.

So all in all, the LCR-T4 may not be a complete replacement for the *SemTest*, but it will undoubtedly make a very handy companion tester.

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Max's Cool Beans

By Max the Magnificent

Flashing LEDs and drooling engineers – Part 25

I'm sure you are familiar with the age-old adage that goes something along the lines of: 'Unexpectedly pleasurable events boost dopamine release, which causes your internal clock to run faster'. Of course, you may be more familiar with the modern version: 'Time files when you're having fun'. Whoever said this certainly knew what they were talking about because I'm currently having so much fun that I don't have any free time left at all; for example…

Hello XIAO BLE Sense

In an earlier *Cool Beans* column (*PE*, July 2020), I introduced the Seeeduino XIAO microcontroller development board (**https://bit.ly/3ckK31c**). Costing only around US$5 and the size of a small postage stamp, this 14-pin beauty boasts a 32-bit Arm Cortex-M0+ processor running at 48MHz with 256KB of Flash memory and 32KB of SRAM.

I love this this little rascal. I used my first XIAO to power my *12x12 Ping-pong Ball Array*, and I've employed these little scamps on numerous projects since. In a later *Cool Beans* (*PE*, January 2021), I augmented the XIAO in the *Ping-pong Ball Array* with one of Adafruit's 9DOF (nine degrees of freedom) Fusion breakout boards (BOBs) (**https://bit.ly/3dP8EwU**). This allowed me to 'roll' a ball around the array by detecting the amount of tilt.

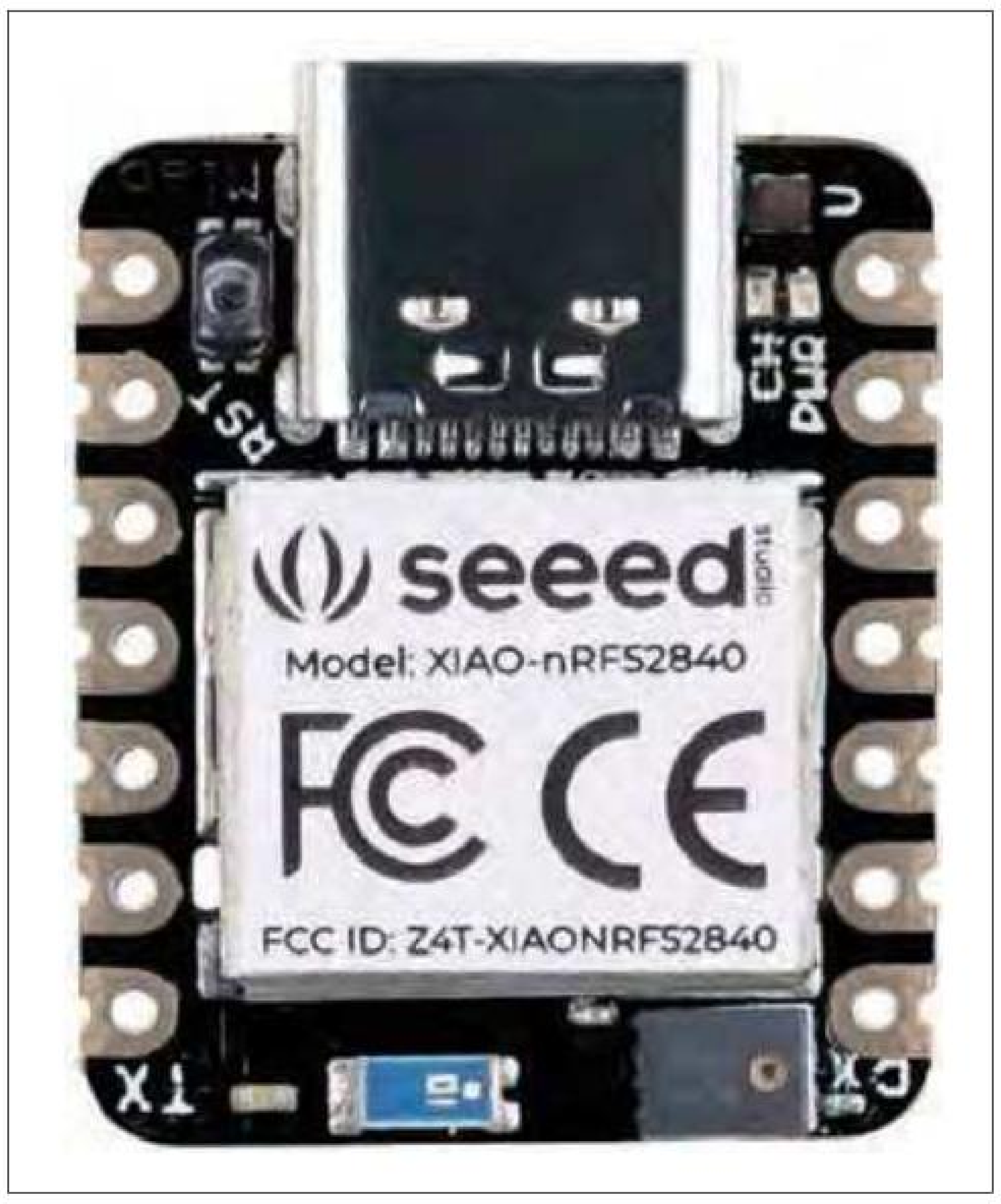


Fig.1. XIAO BLE Sense.

Well, I just heard that the guys and gals at Seeed have introduced the XIAO BLE development board, which is the same formfactor as the original XIAO while including Bluetooth capability and incorporating an onboard Bluetooth antenna (**https://bit.ly/34tp6SV**). Costing only around US$10, this little scamp is based on the Nordic nRF52840, 32-bit ARM Cortex-M4 processor with floating-point unit (FPU) running at 64MHz with 2MB of Flash memory and 256KB of RAM.

But wait! – there's more, because they've also introduced the XIAO BLE Sense (**https://bit.ly/33c4zkX**). Costing only around US$15, this little rapscallion is based on the same processor as the XIAO BLE, but it also includes an onboard microphone and onboard 6DOF inertial measurement unit (IMU), which itself boasts a 3-axis accelerometer and 3-axis gyroscope (Fig.1).

Do you remember how I said earlier that I'm currently having so much fun that I don't have any free time available? Well, as proof of this, the chaps and chapesses at Seeed kindly offered to send me some XIAO BLE Sense boards to play with, but I regretfully felt honour-bound to decline because I simply don't have the time to do them justice.

Panning, tilting, and cocking

As you may recall, we left my previous column (*PE*, February 2022) on something of a cliff-hanger with respect to the progress we're making on our current project to create an animatronic robot head with the ability to pan, tilt and cock, along with two eyes that can themselves pan and tilt on an individual basis.

Just to make sure we're all tap-dancing to the same skirl of the bagpipes – and as I noted when closing the aforementioned column – 'When I say *we*, I mean me and my friend Steve Manley. And when I say, *all of the progress we've been making*, I really mean all of the progress Steve has been making, because he's storming ahead with something so super that you will squeal with delight when you see it.'

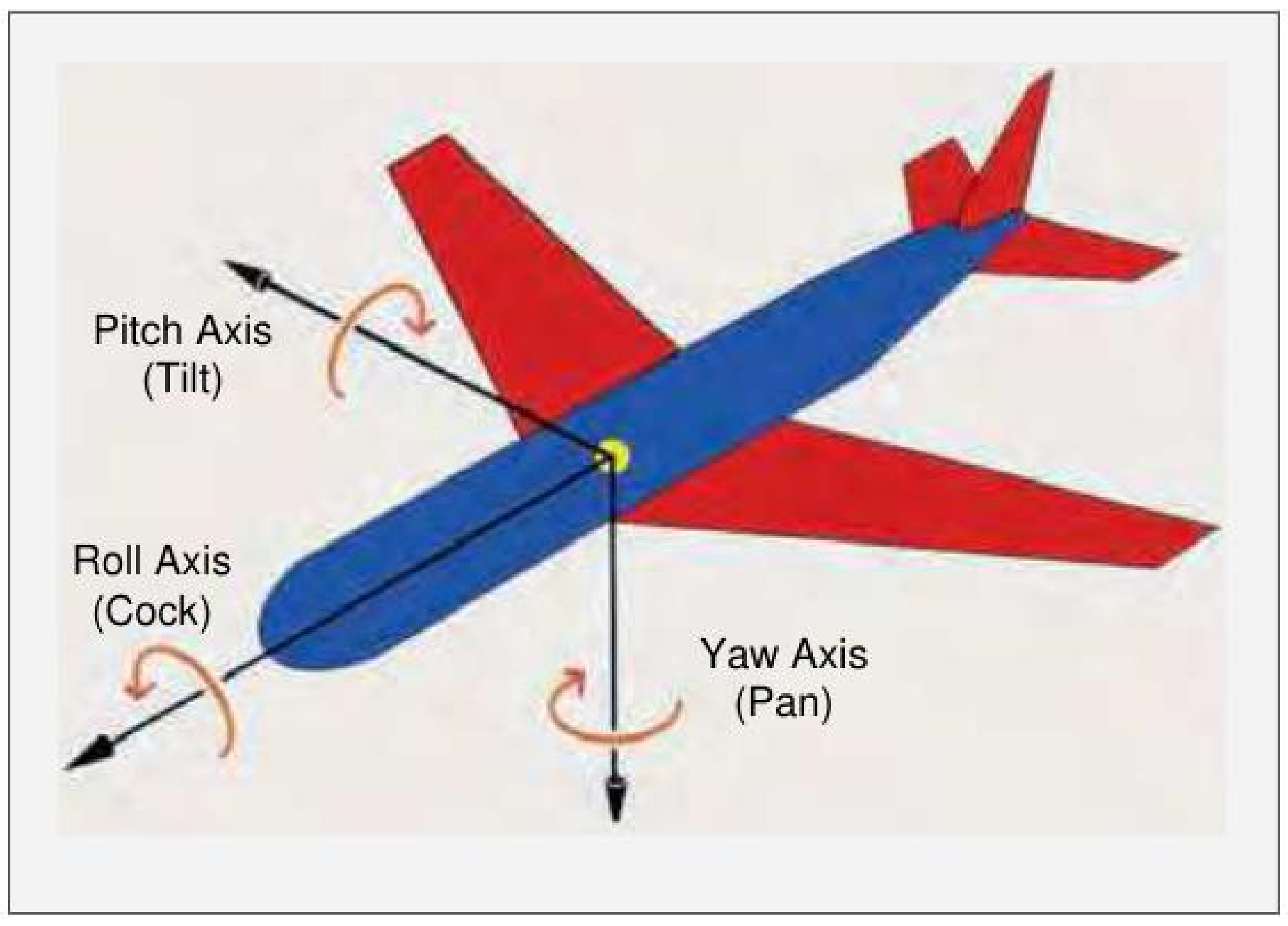


Fig.2. Panning, tilting, and cocking nomenclature.

Fortuitously, this provides the perfect point for us to ponder our nomenclature. When I say 'pan' and 'tilt,' I'm using the terminology associated with the devices upon which movie and television cameras are mounted. These pan-and-tilt heads allow the camera to be rotated in a horizontal plane (pan) or in a vertical plane (tilt). Similarly, our robot head will be able to pan from side to side and/or tilt forward and backward.

The thing is, our robot head is also going to support rotation around a third axis, which would be called the roll axis in an aeronautical context (Fig.2). Our panning motion corresponds to the yaw axis and our tilting motion corresponds to the pitch axis, but what term should we use to reflect the roll axis?

You wouldn't believe how much time I can spend – some may say 'waste' (thank you mother for your continued support) – cogitating and ruminating on this sort of thing. We can't use 'tilt' because we're already employing that to represent leaning forward or backward. We might consider 'lean,' but that could also be interpreted as leaning forward or backward. I could be tempted to use 'roll,' but we are also planning on supporting pan-and-tilt with our robot's eyes, and – when someone is said to 'roll their eyes' – this typically involves them briefly turning their eyes upward (albeit oftentimes combined with an arcing motion), which could be confused with our tilting movement. Ultimately, I settled on 'cock' because 'cocking your head' means to turn the

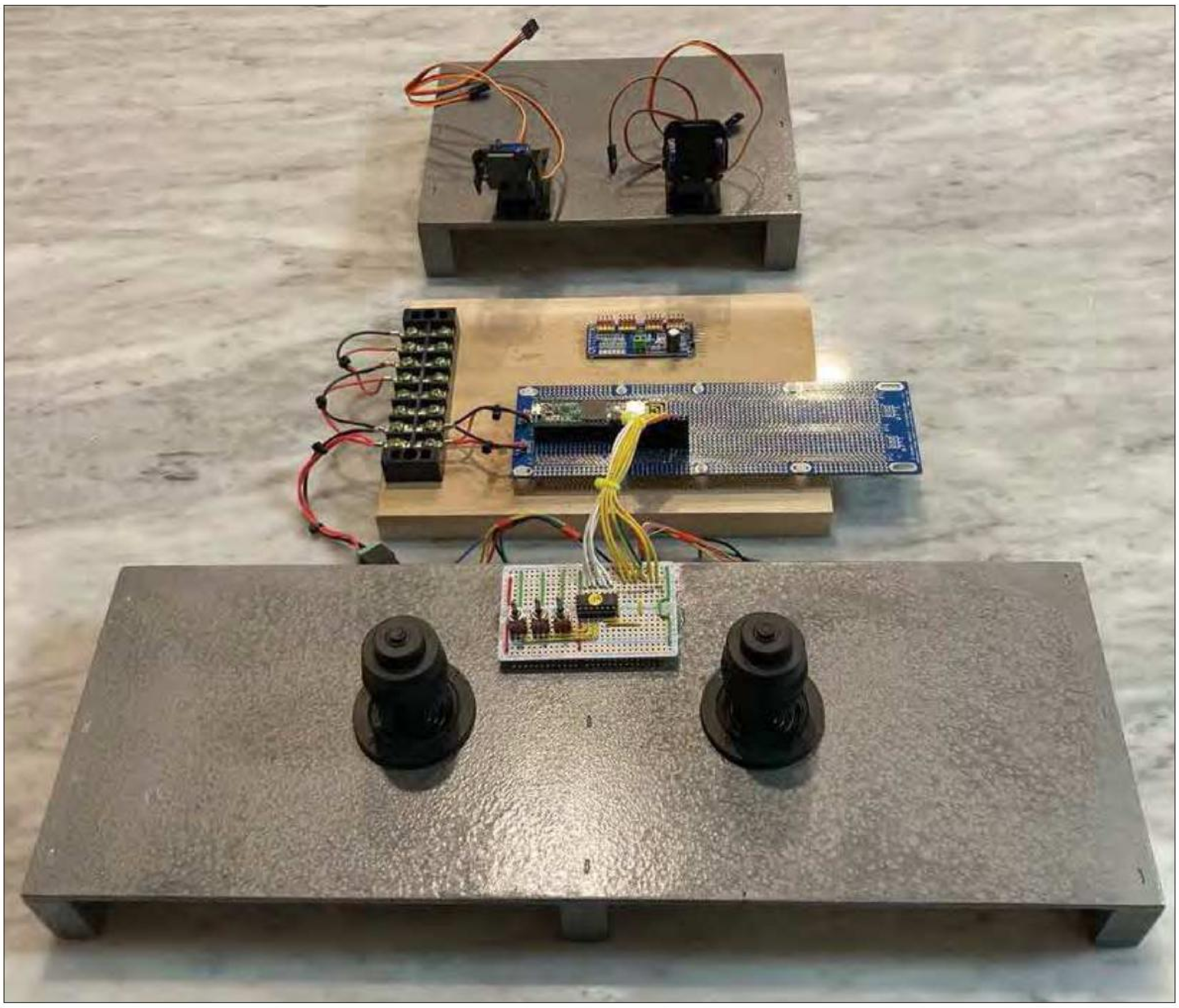


Fig.3. The current state of play with respect to my testbench.

top of the head down to the left or right such that one of the ears moves closer to its associated shoulder. Having said this, I'm not proud (have you seen the way I dress?) and I'm open to suggestions, so please feel free to drop me an email if you can think of anything that's more appropriate.

A tempting teaser

A couple of months ago, when Steve and I originally commenced to ponder the problem of creating an animatronic robot head, I decided to forge ahead with a simple testbench that I could throw together quickly and easily (Fig.3). Unfortunately, quickly and easily has translated into slow and painful due to my being so easily distrac... Squirrel! Be this as it may, we will contrast and compare my humble creation (I pride myself on my humility) with Steve's far superior offering later in this column.

The shallow grey platform (which is made from spray-painted wood) in the foreground of Fig.3 is used to hold the multi-axis joysticks we introduced in a previous column (*PE*, January 2022). Each of these joysticks contains three 10kΩ potentiometers (pots). The first pot changes its resistance in response to a forward-backward motion of the joystick, the second to a left-right motion, and the third to a twisting clockwise-anticlockwise motion. Each joystick also has a pushbutton on the top.

The small prototyping board between the joysticks is used as a staging point to gather all the wires from the pots and pushbuttons before handing them over to the microcontroller unit (MCU). This board also carries three small toggle switches and a 6-channel LogiSwitch LS119-P integrated circuit (IC) presented in a 14-pin dual in-line (DIL) package (**https://bit.ly/3sNyDhC**). In addition to debouncing the three toggle switches, this chip is also used to debounce the two pushbutton switches on the joysticks.

The wooden platform in the middle of Fig.3 carries one of the blue prototyping boards Steve and I conceived as part of our 10-character, 21-segment Victorian display project (*PE*, August 2021). At the moment, this board carries only a Teensy 3.6 MCU, which boasts a 32-bit 180MHz Arm Cortex-M4F processor with 58 input/output (I/O) pins (25 of which can act as analogue inputs if required), 1MB of Flash memory, and 256KB of RAM (**https://bit.ly/3FNic8E**).

The reason I'm using a Teensy 3.6 to drive my prototype – as opposed to a Seeeduino XIAO, for example – is that it has more pins. And the reason I'm using this standalone processor– as opposed to the sophisticated control board with which Steve is working – is that it's easier to wrap our brains around and I want you to be able to replicate what I'm doing if you so desire. In the fullness of time, this MCU will be used to drive the 16-channel servo control board seen at the back of the wooden platform. In turn, this control board will be used to drive the two pan-and-tilt mechanisms mounted on the grey platform seen in the rear of Fig.3.

Compound operators

In the sketches (programs) we've perused and pondered in previous columns, we've predominantly restricted ourselves to using the simple '=' assignment operator. For example, if we wanted to add 3 to an integer variable called `a`, we've employed a statement like the following: `a = a + 3;`

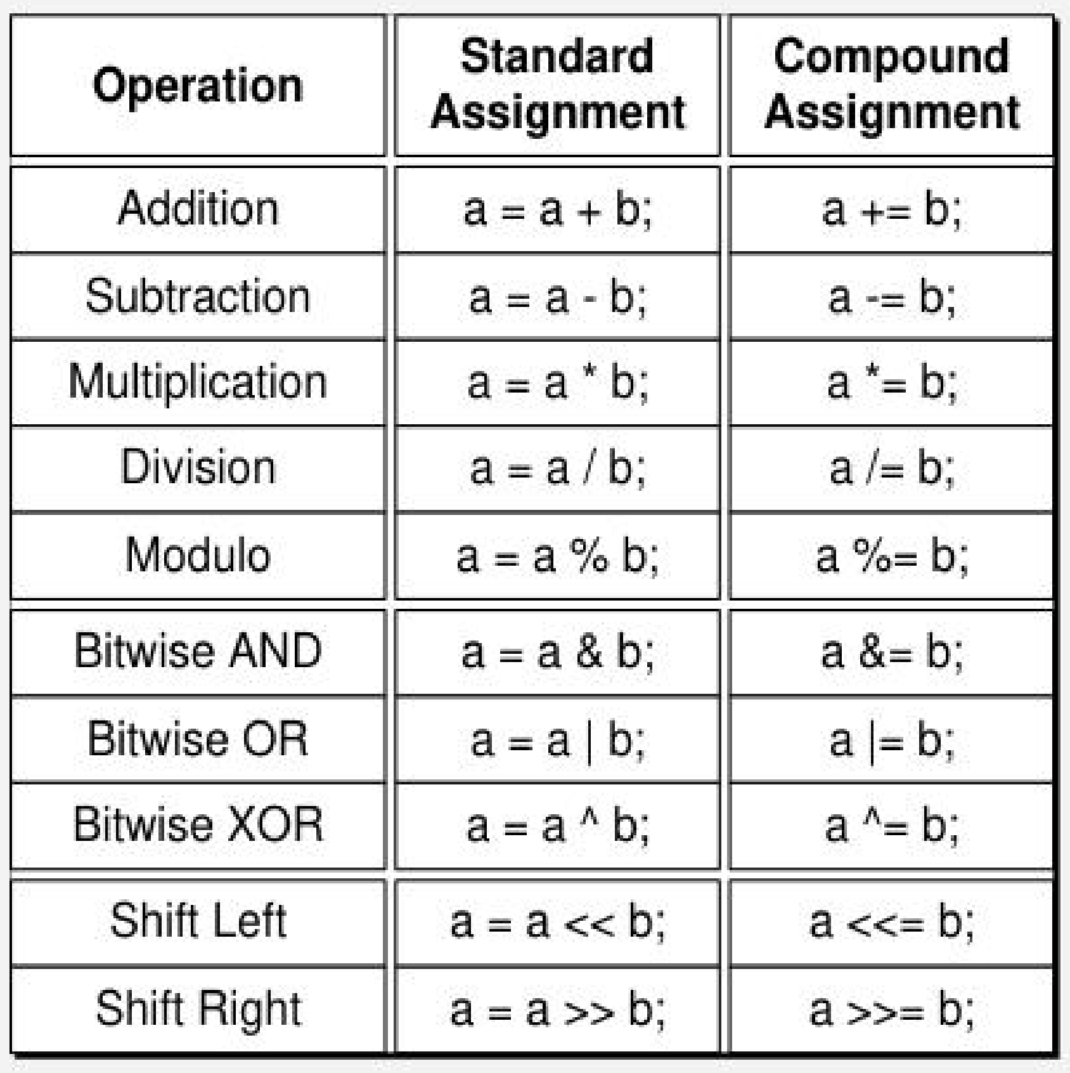
A more concise way of saying exactly the same thing is to use a compound assignment operator as follows: `a += 3;`

Compound assignment operators provide a shorter syntax for assigning the result of an arithmetic or bitwise operation. We've not used these before because they can be confusing the first time you see them, but you soon get used to them and they can help streamline the look of your code.

You will see these compound assignment operators in the sketches discussed later in this column. In the meantime, a summary is provided in Fig.4.

Bouncy wouncy

Let's return to consider the two pushbutton switches on the top of the joysticks and the three toggle switches on the small prototyping board mounted between the joysticks. The thing about switches – including toggle switches and pushbutton switches – is that they 'bounce' when they change state from off to on, or vice versa (Fig.5).



Operation	Standard Assignment	Compound Assignment
Addition	a = a + b;	a += b;
Subtraction	a = a - b;	a -= b;
Multiplication	a = a * b;	a *= b;
Division	a = a / b;	a /= b;
Modulo	a = a % b;	a %= b;
Bitwise AND	a = a & b;	a &= b;
Bitwise OR	a = a | b;	a |= b;
Bitwise XOR	a = a ^ b;	a ^= b;
Shift Left	a = a << b;	a <<= b;
Shift Right	a = a >> b;	a >>= b;

Fig.4. Summary of compound assignment operators in C.

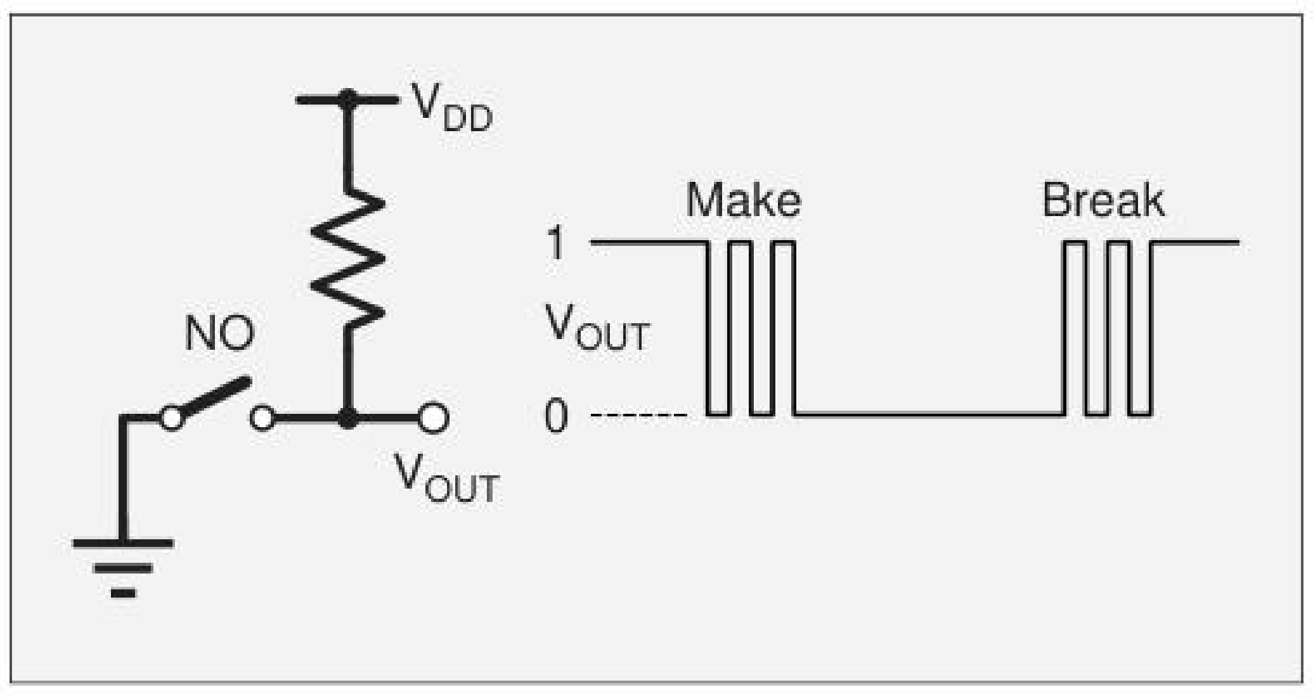


Fig.5. SPST toggle switch with a pull-up resistor.

The symbol we are using for the switch in Fig.5 indicates a normally open (NO) single-pole, single-throw (SPST) toggle switch. In this example, one side of the switch, which we might think of as being the input, is connected to ground (0V), while the other side, which we might think of as being the output, is connected to V_{DD} (+ve) via a pull-up resistor. When the switch is in its inactive or open state, V_{OUT} is pulled to a logic 1 by the pull-up resistor. When the switch is in its active or closed state, V_{OUT} is connected to logic 0 (ground).

Having the input to the switch connected to ground coupled with a pull-up resistor on its output is a common scenario and it's the way we will be doing things throughout this project. It's worth noting, however, that an alternative approach would be to connect the input of the switch to V_{DD} (+ve) and connect its output to ground via a pull-down resistor. In this case, an inactive/open switch would result in V_{OUT} being 0, while an active/closed switch would result in V_{OUT} being 1.

If I were doing this sort of thing using discrete pull-up or pull-down resistors, I would typically employ 10kΩ components, but anything between 1kΩ and 10kΩ will suffice.

The main thing to note for the purposes of these discussions is that when we close the switch (we also use the term 'make' as in 'make the connection'), the spring-loaded mechanical contact inside the switch may bounce back and forth between 0 and 1 values multiple times before finally settling into a 0 state. Similarly, when we subsequently re-open the switch (we also use the term 'break' as in 'break the connection'), the contact may once again bounce back and forth between 1 and 0 values multiple times before eventually settling on a 1.

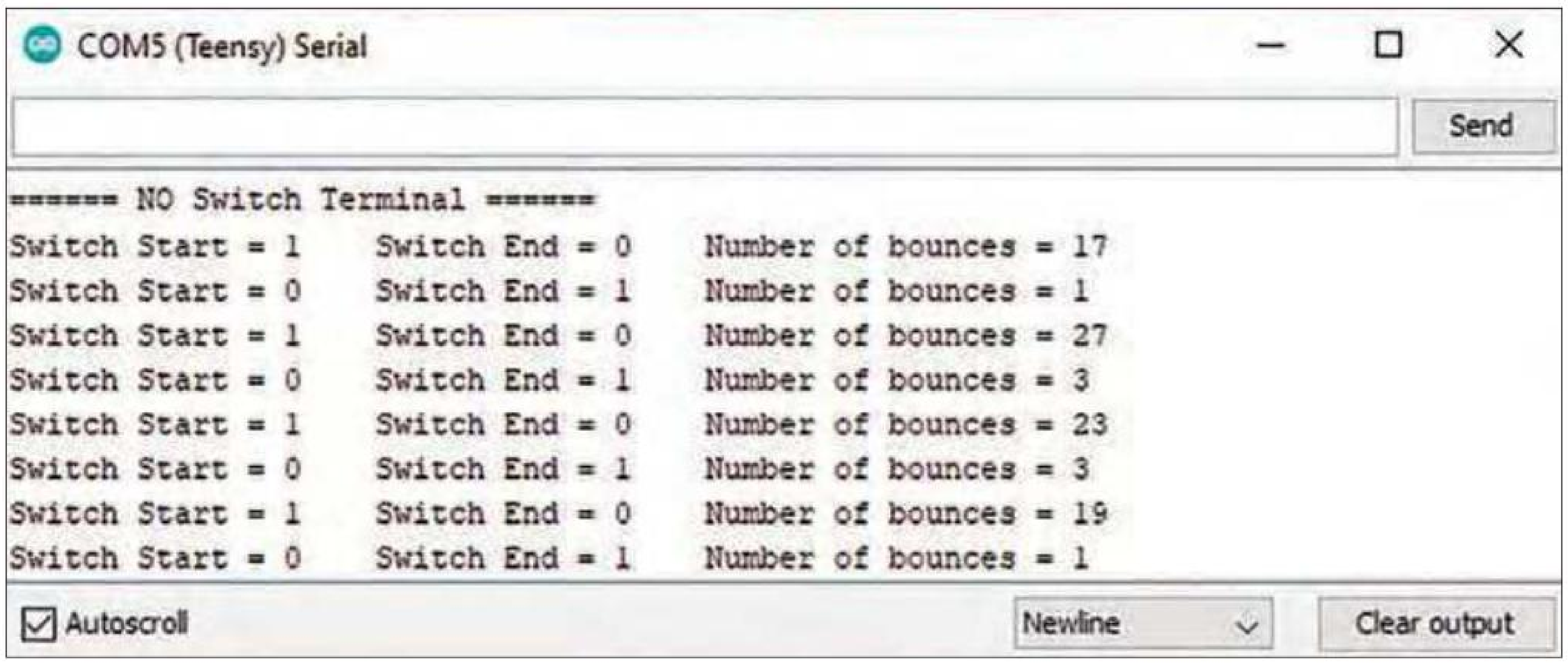
How many?

It's easy to say things like 'multiple times' as we did in the previous section, but what does this actually mean? Well, in practice, this can be anything between 1 and 100+ bounces depending on the switch. The *specific* number of bounces can vary every time we use the switch and, just to increase the fun and frivolity, the *average* number can change depending on environmental conditions (humidity, temperature) and it can evolve over time as the switch ages.

Just for giggles and grins, I pulled an SPST toggle switch out of my box of bits and soldered two short flying leads onto its terminals. I then connected one terminal to ground and the other to digital I/O pin 14 on my Teensy 3.6.

For reasons that will become clear in a moment, I wanted to test the state of my switch for a period of more than 6.2 milliseconds (ms), so I targeted 10ms as being a nice round number. The first thing I did was create a simple sketch that (a) saves the start time in microseconds (µs), (b) loops around performing a specified number of digital reads on the MCU pin connected to the switch, (c) saves the end time in µs, (d) calculates the total time (end time – start time) spent executing the loop, and (e) displays this total time on the serial monitor. The first time I did this, I set the loop count to 10,000, which gave me a total time of 1,112µs (1.112ms). Based on this, I boosted the loop count to 100,000, which gave me a total time of 11,120µs (11.12ms), which is more than the 10ms I was looking for. If you wish, you can download this code (file **CB-Mar22-01.txt**) from the March 2022 page of the *PE* website (**https://bit.ly/3oouhbl**).

Next, I used the intelligence acquired from my first program to create a modified version that counts the number of times the switch bounces (file **CB-Mar22-02.txt**). (If you keep your eyes open, you'll observe the use of the compound assignment statement `numBounces += 1;` in this sketch). This new program starts off by reading the initial on/off state of the switch in the `setup()` function. When we get to the `loop()` function, we stooge around waiting for the switch to transition to its complementary off/on state, which tells us that the switch has been activated or deactivated. This is the point that we start to loop around 100,000 times (which we know is more than 10ms) counting the number of bounces. After reporting the results to the Serial I/O window, we do the whole thing over and over again (Fig.6).



```
====== NO Switch Terminal ======
Switch Start = 1   Switch End = 0   Number of bounces = 17
Switch Start = 0   Switch End = 1   Number of bounces = 1
Switch Start = 1   Switch End = 0   Number of bounces = 27
Switch Start = 0   Switch End = 1   Number of bounces = 3
Switch Start = 1   Switch End = 0   Number of bounces = 23
Switch Start = 0   Switch End = 1   Number of bounces = 3
Switch Start = 1   Switch End = 0   Number of bounces = 19
Switch Start = 0   Switch End = 1   Number of bounces = 1
```

Fig.6. Counting the number of bounces on an SPST toggle switch.

In this example, with this switch, the act of closing (making) the switch resulted in the most bounces (17, 27, 23, 19...), while opening (breaking) the switch generated fewer bounces (1, 3, 3, 1...). Having said this, I played with the switch more than is shown here, and closing the switch sometimes resulted in as few as 10 bounces while opening the switch generated as many as 7 bounces on one occasion.

How long?

How long does this bouncing persist? This is a tricky one because different people will tell you different things. When I was starting my career, for example, a more experienced engineer told me that any bouncing was sure to have finished by 1ms after the switch was first activated. He was wrong. A couple of years ago, one of my chums – embedded systems guru Jack Ganssle – pulled a selection of 20+ switches of various shapes and sizes out of his spare parts box and evaluated them on his workbench. Jack reported that the average bounce duration was 1.6ms, while the worst-case duration was 6.2ms (hence my checking for more than 10ms in my experiments above).

It's one thing when a non-critical system like the pushbutton on a TV remote control bounces, causing you to advance multiple channels instead of one, as annoying as that may be. It's quite another matter if you are trying to save the world and the 'advance one day' button on your time machine bounces like a ping-pong ball. For this reason, people working on mission-critical or safety-critical systems commonly design things to wait for 20ms after the final bounce (to ensure that was indeed the final bounce) before doing anything rash.

Cheap and cheesy

As I noted earlier, in the case of my robot head testbench, I'm using a LogiSwitch LS119-P device to debounce my toggle and pushbutton switches. We've discussed these ICs on a couple of previous occasions (*PE*, April 2019 and March 2020).

But what would we do if we didn't have one of these chips to hand? Well,

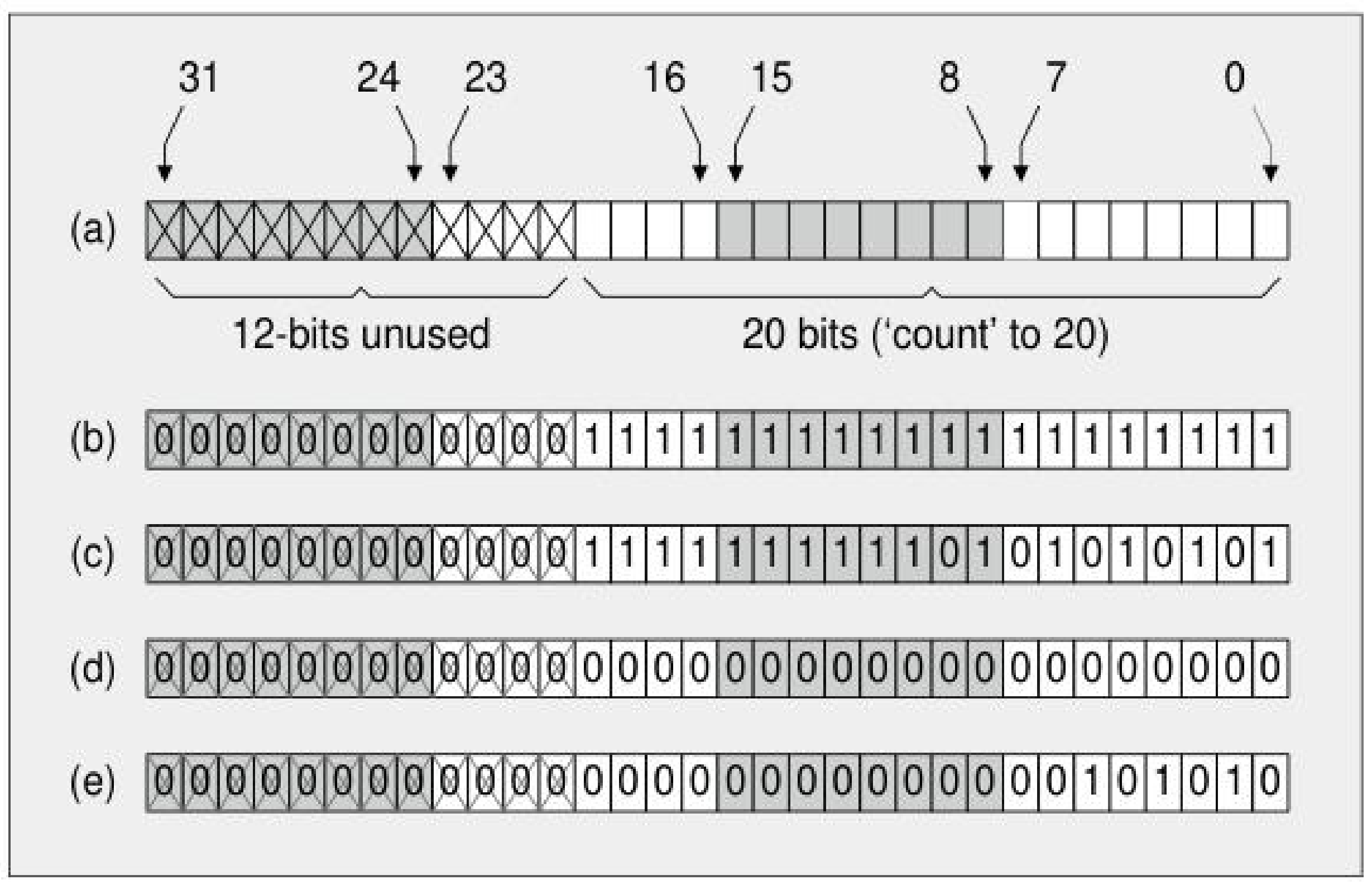

31
24
23
16
15
8
7
0
(a)
12-bits unused
20 bits ('count' to 20)
(b) 00000000000011111111111111111111
(c) 00000000000011111111110101010101
(d) 00000000000000000000000000000000
(e) 00000000000000000000000000101010

Fig.7. Debouncing with a 32-bit unsigned integer as a shift register.

we could debounce the signal coming from the switch in hardware using a resistor-capacitor (RC) delay circuit, for example (*PE*, April 2019). Alternatively, we could debounce the signal from the switch in software running on our MCU. In this case, we could (and we do) replace our discrete pull-up resistor by declaring this MCU input as being of type `INPUT_PULLUP`, which causes an internal pull-up resistor to be applied to this pin.

There are myriad techniques for handling switch bounce in software. Some of them even work. For the sake of simplicity, let's assume we are working with a single switch, although everything we're going to discuss can easily be scaled to handle multi-switch scenarios.

If we assume that our switch starts off in its inactive state, and that all our program is required to do is wait for this switch to be activated and then cause something to happen, we might opt for a cheap and cheesy approach. In this case, all we really need to do is loop around waiting for the switch to transition from its inactive to active state, after which we do whatever it is that needs to be done.

What about if our system is in an electrically noisy environment where the MCU's input may experience an occasional glitch in the form of a spike, which could be perceived as being a transition to the switch's active state? In this case, we can start by looping around waiting for the first transition, and then wait some amount of time – say 20ms – before checking the state of the switch again. If the switch is still active, we can do whatever it is that we want to do. Alternatively, if the switch has returned to being inactive, then we return to looping around waiting for the start of the real transition.

In reality, of course, our lives are rarely so simple. It's more often the case that we have multiple switches and that our program has lots of things to do in addition to checking the states of these little rascals. It may also be that we wish to perform one set of actions when a switch is activated and a different set of actions when that switch is deactivated.

One approach is to create our program in such a way that it cycles around a master loop once every millisecond, for example. At the beginning of this loop, we can check the state of our switches and perform any switch-related actions if they've transitioned from inactive to active, or vice versa, after which we may perform any non-switch-related actions. The way in which we might implement something like this was introduced in excruciating detail in our *Dump the delay()* discussions (*PE*, December 2020).

For some, counters captivate

Taking the aforementioned loop as a starting point, and assuming once again that we are working with a single switch for simplicity, a common software switch debounce technique involves the use of a counter, which we initialise to contain a count of zero. Suppose our switch starts off in its inactive (logic 1) state as seen by the MCU, which means we are waiting for the switch to transition to its active (logic 0) state. In this case, every time we cycle round our loop and we see a 0 on the switch, we increment (add one to) the counter. By comparison, every time we see a 1 on the switch, we reset the counter to zero. Thus, it's only when the counter reaches a value of 20 in decimal (0x14 in hexadecimal) that we know our switch has been in a stable 0 state for 20ms.

Once the switch is in its active (logic 0) state and we've performed any associated actions, we start looking for it to return to its inactive (logic 1) state. In this case, we increment the counter every time we cycle round our loop and we see a 1 on the switch, and we reset the counter to zero every time we see a 0 on the switch. Thus, it's only when the counter reaches a value of 20 in decimal that we know our switch has been in a stable 1 state for 20ms.

You can look at a simple sketch that does all of this (file **CB-Mar22-03.txt**). (Once again, observe the use of the compound assignment statement `Counter += 1;`).

Also observe that we defined our `Counter` as being an integer variable of type `int`. We've discussed the size of integers – including the fact that they may vary depending on the type of MCU – in earlier *Tips and Tricks* columns (*PE*, August and September 2020). In the case of a Teensy 3.6, an integer is a 32-bit quantity (it's 16-bits in an Arduino Uno).

Since the maximum count we are looking for in this example is 20, if we were working with a small, resource-limited MCU, we might decide to declare our counter as being an 8-bit signed integer, which can represent values in the range –128 to +127, or an 8-bit unsigned integer, which can represent values in the range 0 to 255. The reasons we are using a 32-bit integer – which is overkill with respect to the size of the numbers it can represent – in this sketch are twofold: (a) we aren't resource limited and (b) MCUs function most efficiently when working with their native integer size.

For others, shift registers satisfy

I certainly wouldn't cast aspersions at those who favor counters as their software switch debounce mechanism of choice, but neither would I count myself one of their number (no pun intended). For myself, the radiance of my smile falls on the subtle simplicity of a shift register-based scenario (we introduced the concept of shift registers in the June 2021 *Tips and Tricks* column). Once again, let's assume that we are working with a single switch, in which case we will need only one shift register.

As we see (file **CB-Mar22-04.txt**), this new sketch uses the same loop technique as our previous program. Instead of using a counter, however, we employ a 32-bit unsigned integer (type `uint32_t`) in the role of a shift register. In fact, we need only 20 bits to count to 20, so the 12 most-significant bits (MSBs) remain unused (Fig.7a).

Suppose our switch starts off in its inactive (logic 1) state as seen by the MCU, which means we are waiting for the switch to transition to its active (logic 0) state. In this case, we will initialise the 20 least-significant bits (LSBs) in our shift register to contain 1s, while the 12 MSBs will be loaded with 0s (Fig.7b).

In certain respects, things are simpler than with the counter technique because all we have to do at the start of each loop is shift the contents of the register one bit to the left, load (via a bitwise OR ('|') operation) the current value on the switch into the LSB (that is, bit 0), and use a mask (via a bitwise AND ('&') operation) to clear the 12 MSBs to 0. (We introduced logical bitwise operations in our *PE* March 2021 *Tips and Tricks* column.) We achieve all this using three statements, each of which employs a compound assignment as follows:

```
ShiftReg <<= 1;
ShiftReg|= digitalRead(PinSw);
ShiftReg &= SR_MASK;
```

To a large extent, we don't care what's happening on the switch because this technique is great at filtering out noise spikes and suchlike. For example, suppose the switch starts to go active and commences by bouncing five times. Assuming – purely for the sake of these

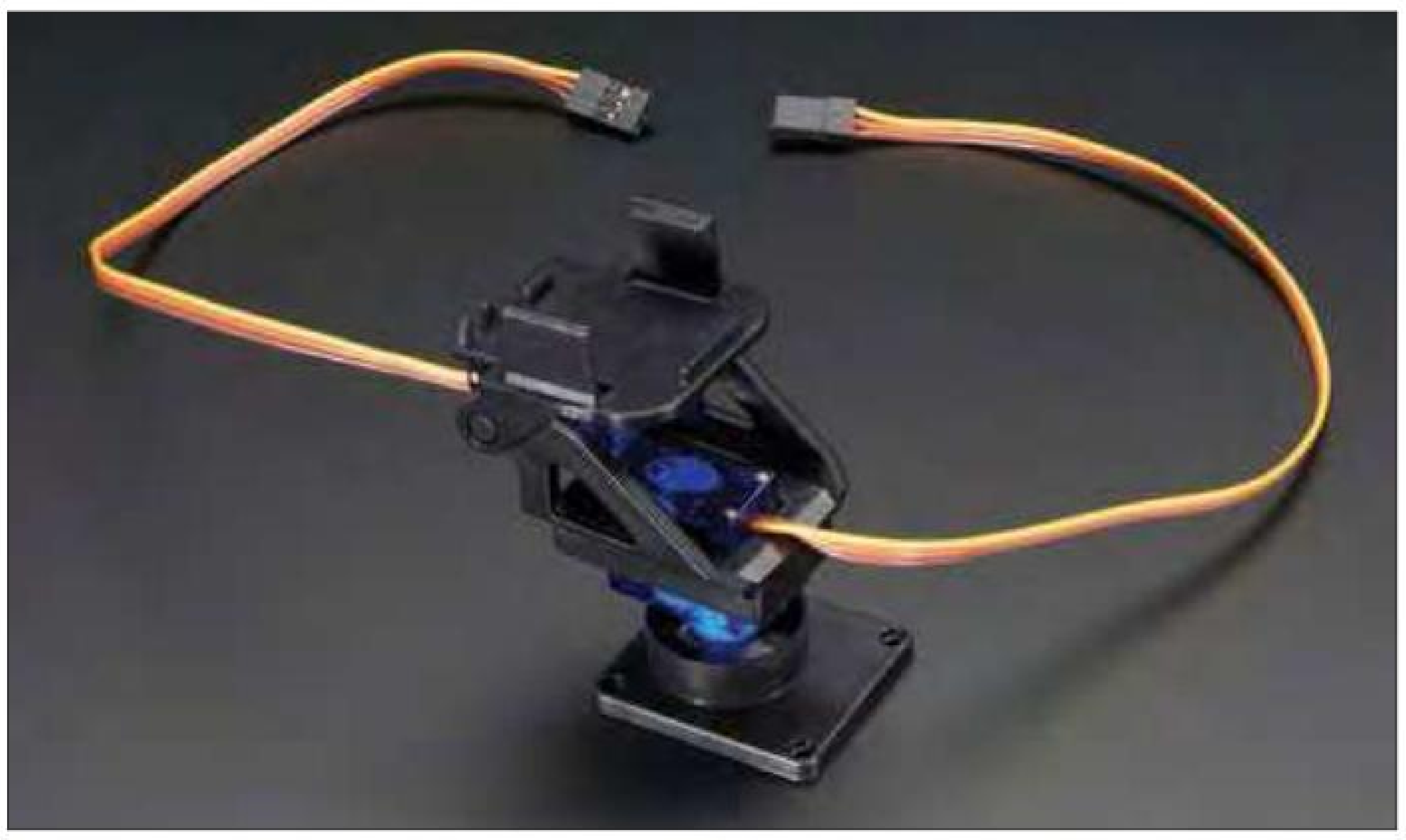


Fig.8. In this traditional implementation, the pan and tilt motions are mechanically isolated.

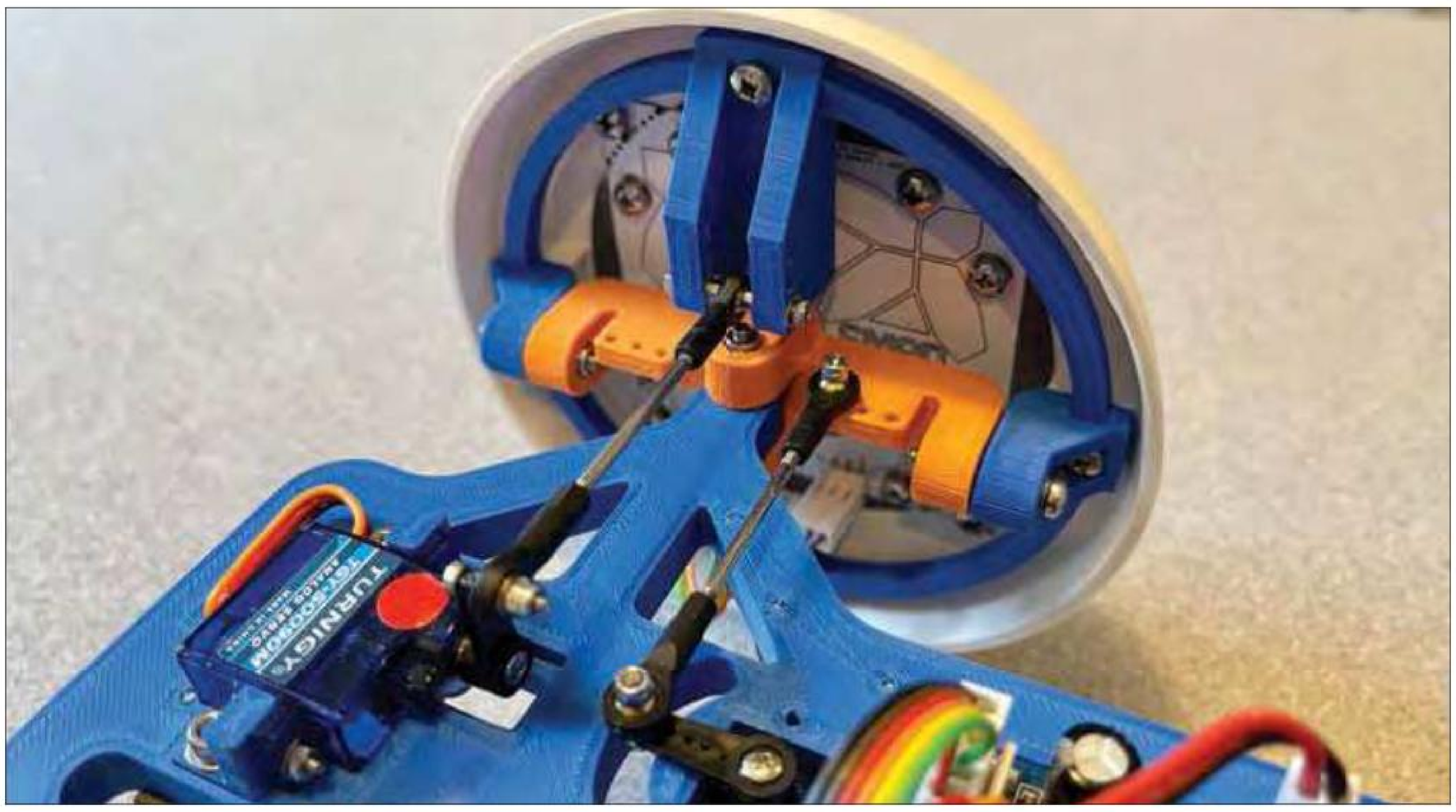
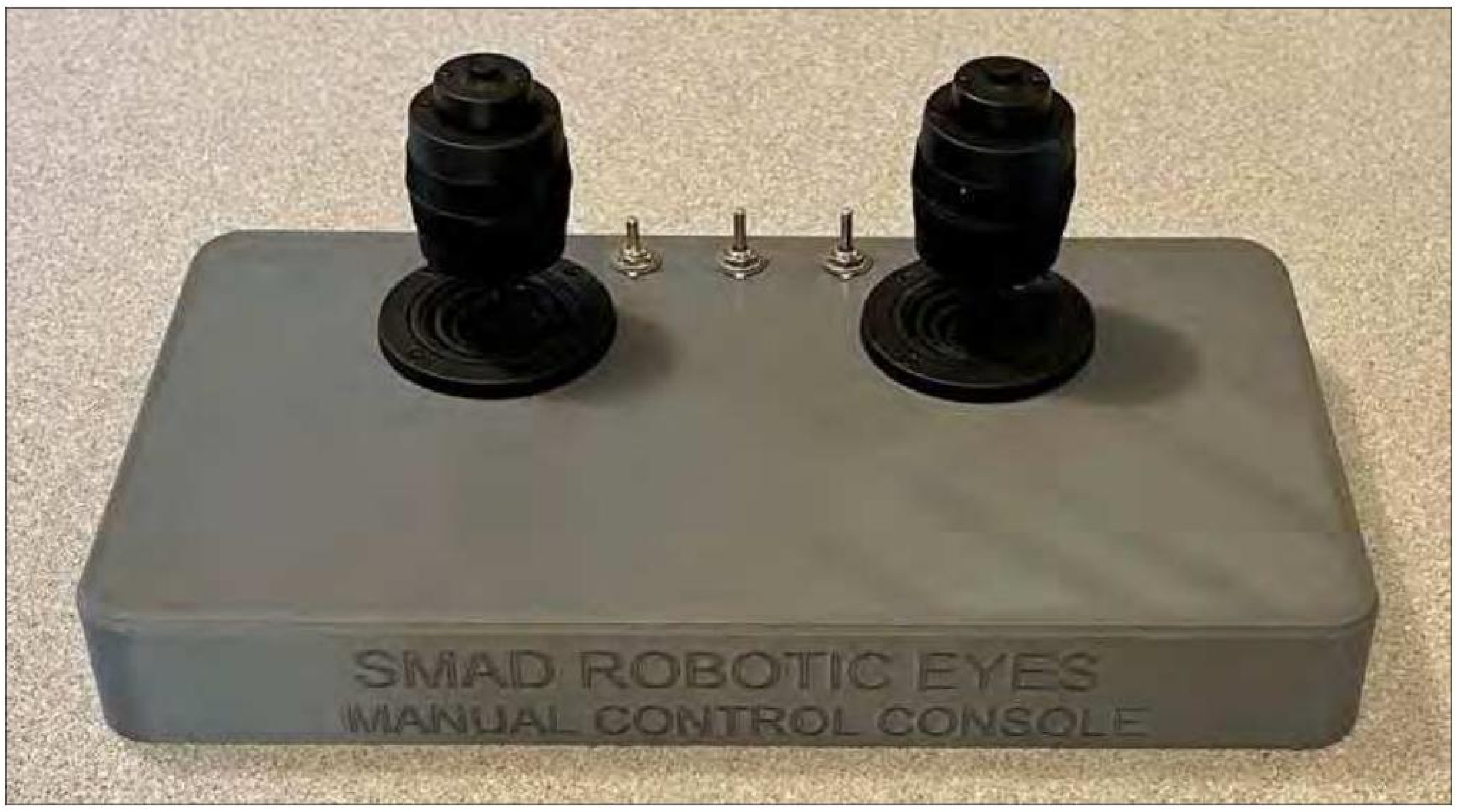


Fig.9. The two servos controlling one *SMAD* eye. (Image source: Steve Manley)



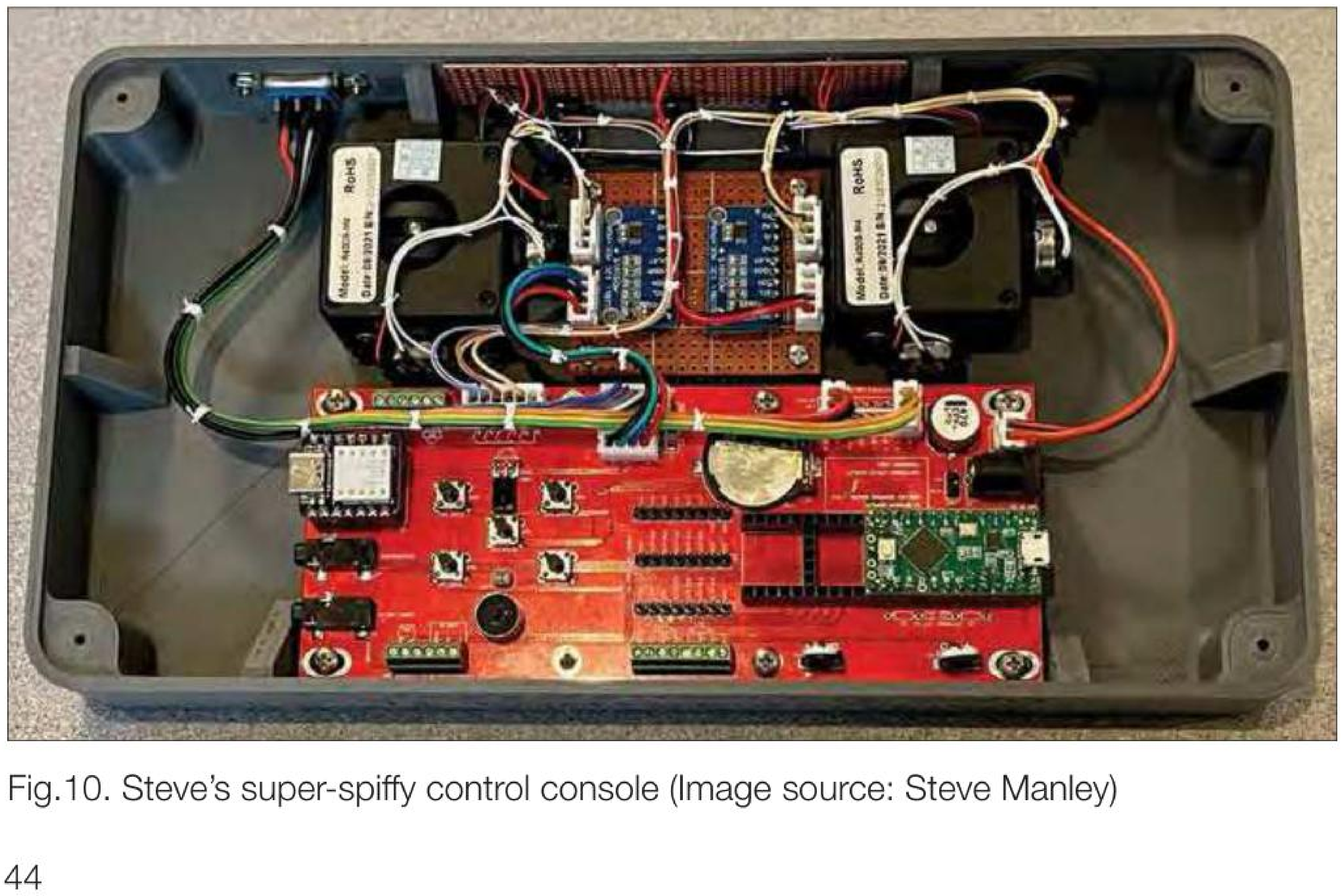


Fig.10. Steve's super-spiffy control console (Image source: Steve Manley)

discussions – that each bounce takes a millisecond, this would appear in the shift register as illustrated in Fig.7c. This doesn't affect us at all. We just keep on cycling around our loop until the 20 LSBs of the shift register all contain 0s. Coupled with the fact that we're forcing the 12 MSBs to 0, this equates to 0x00000000 in hexadecimal (Fig.7d), which informs us that our switch has been in a stable 0 state for 20ms.

Once the switch has arrived in its active (logic 0) state and we've performed any associated actions, we start looking for it to return to its inactive (logic 1) state. In this case, we might be tempted to start by initialising the shift register with all 0s, but we don't need to do this because it already contains all 0s from when we were waiting for the switch to be activated (Fig.7d).

The shift register will continue to contain all 0s as long as the switch remains active. Now, suppose the switch starts to go inactive and commences by bouncing three times. Assuming once again that each bounce takes a millisecond, this would appear in the shift register as illustrated in Fig.7e. This time, we just keep on cycling around our loop until the 12 MSBs of the shift register contain 0s and the 20 LSBs of the shift register contain 1s. This equates to 0x000FFFFF in hexadecimal (Fig.7b), which informs us that our switch has been in a stable 1 state for 20ms. (I don't know about you, but I feel like singing 'Tra-la!')

Did you realise that…

It's easy for beginners – and professionals, for that matter – to forget that anything we can implement in software can be realised in hardware, and vice versa.

On this basis, it just struck me that it is perhaps worth pointing out that both the counter- and shift register-based software debounce techniques presented above could also be implemented in hardware (how do you think the aforementioned LogiSwitch ICs perform their magic?).

Feast your orbs

I fear we are once again approaching the end of the column. Before we go, however, I want to give you a sneak peak at some of the things Steve has been working on with regard to his 'official' (full Monty) animatronic head.

Let's start by returning to the two pan-and-tilt mechanisms I'm using on my progressively parsimonious prototyping platform – the ones we saw mounted on the small wooden platform at the rear of Fig.3. These are Mini Pan-Tilt Kits with Micro Servos from Adafruit (**https://bit.ly/3f4FjjC**). Each of these mechanisms will carry one of the *SMAD* (*Steve and Max's Awesome Display*) boards we've been discussing in our *Cool Beans* columns for the past couple of months. The point is that these are implemented in the same way as every pan-and-tilt mechanism I've ever seen, with the two motions mechanically isolated from each other. In this case, the tilt servo sub-assembly is mounted on top of the pan servo sub-assembly (Fig.8).

This is where things get interesting. There are many cases in the history of technology where seasoned professionals professed that something couldn't be done. Being unaware of this, however, their inexperienced junior counterparts ambled off and did it anyway.

This is not to imply that Steve is my junior in any way, you understand. It's just that he's never worked with a servo-driven pan-and-tilt mechanism before. Thus, when I first described the sort of motion we were looking for, with each eye being able to pan and tilt on an individual basis, Steve came up with an implementation of such awesome cunning that it brings a tear of joy to my naturally panning and tilting eye (Fig.9).

This image shows a view of one of the *SMAD* eyes from the back of the robot's head. The interesting thing is the way in which Steve is using two servos attached to the main 3D printed frame to drive a universal joint attached to the eye. And the amazing thing is the way in which the pan and tilt motions manage to remain isolated from each other.

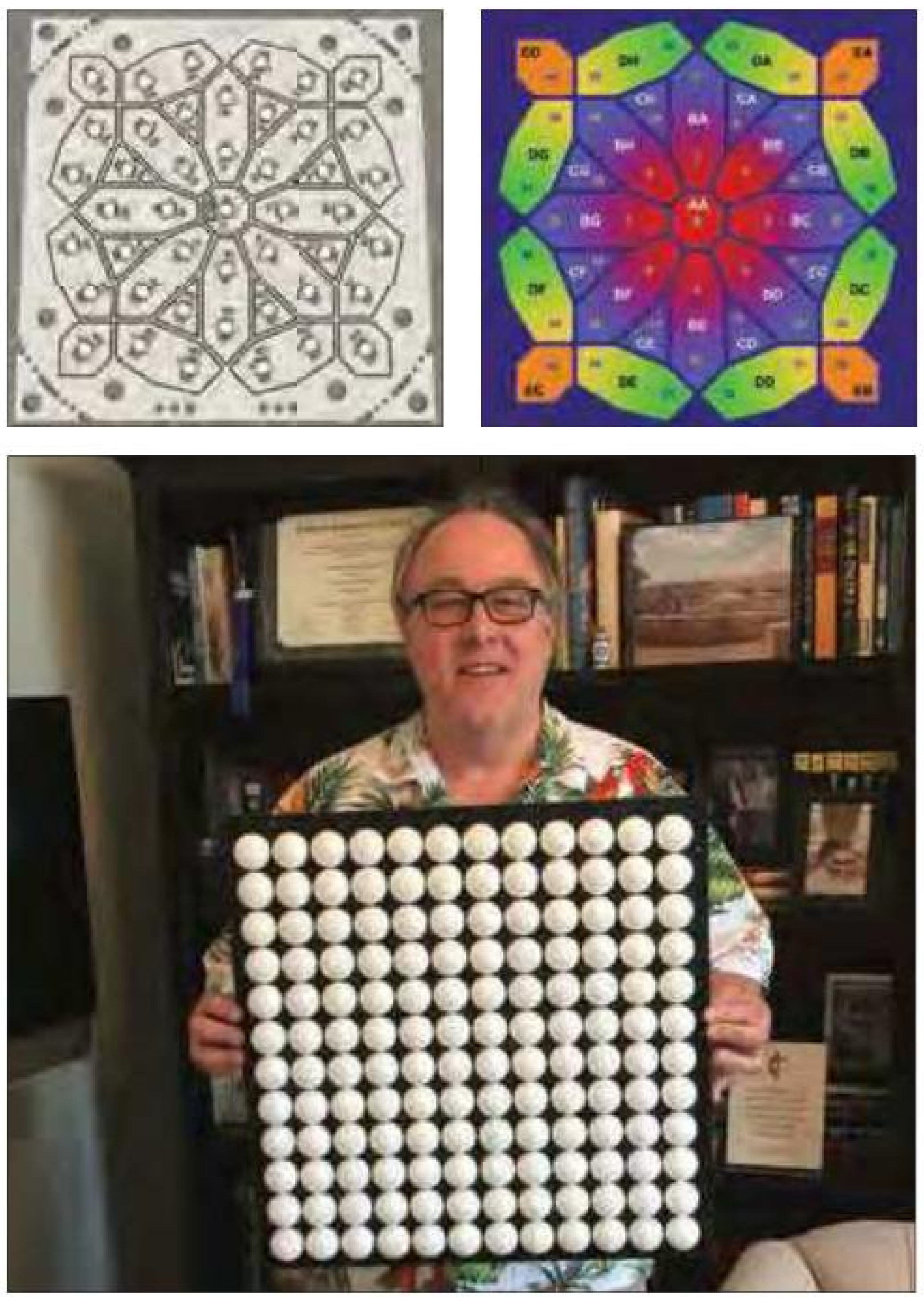
Steve created an animation showing this in action and he kindly allowed me to post it to my *Cool Beans Blog* channel on YouTube (**https://bit.ly/3GcVTJK**). I've shown this animation – along with another video of the real assembly working – to several of my engineering friends, and we all agree that we've never seen anything like it before.

Last, but certainly not least, let's return to the platform holding my joysticks in the foreground of Fig.3 and the wooden platform carrying my microcontroller and servo control board in the middle of Fig.3. Now compare and contrast this with Steve's equivalent (Fig.10).

Steve fabricated this enclosure on his 3D printer, and it has to be acknowledged that it looks much more professional than my humble offering. The large red board inside this enclosure is one of the control boards Steve developed to drive our Victorian displays. As described in a previous column (*PE*, July 2021), this board boasts myriad capabilities, including supporting infrared (IR) control and the ability to make the tricolor LEDs on the *SMADs* respond to sound.

Next month

We will be exploring both my and Steve's animatronic offerings in more detail in my next column. Until then, as always, I welcome your captivating comments, thought-provoking questions, and insightful suggestions.



Want to build your own amazing *Ping-pong Ball Array* or *SMAD?* All the details are in previous *Cool Beans* columns, starting in March 2020.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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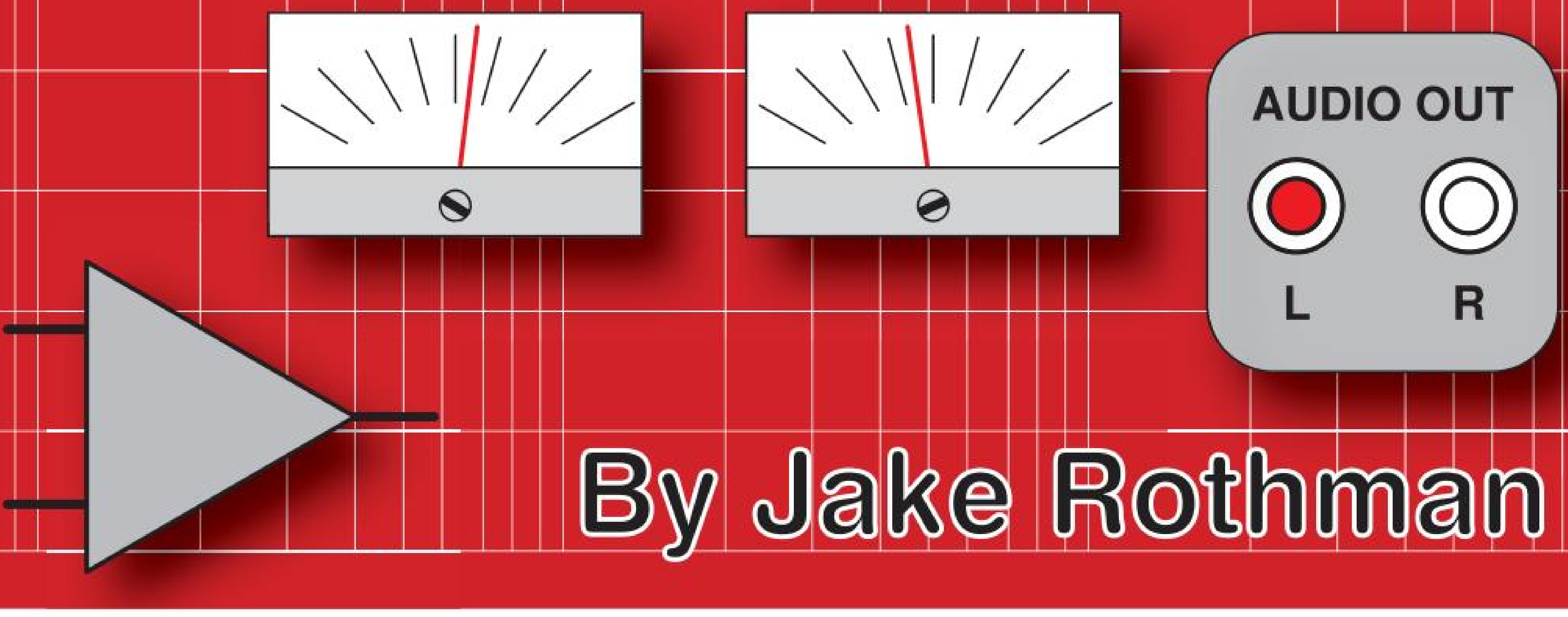
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By Jake Rothman

Analogue Vocoder – Part 5: Building the filters

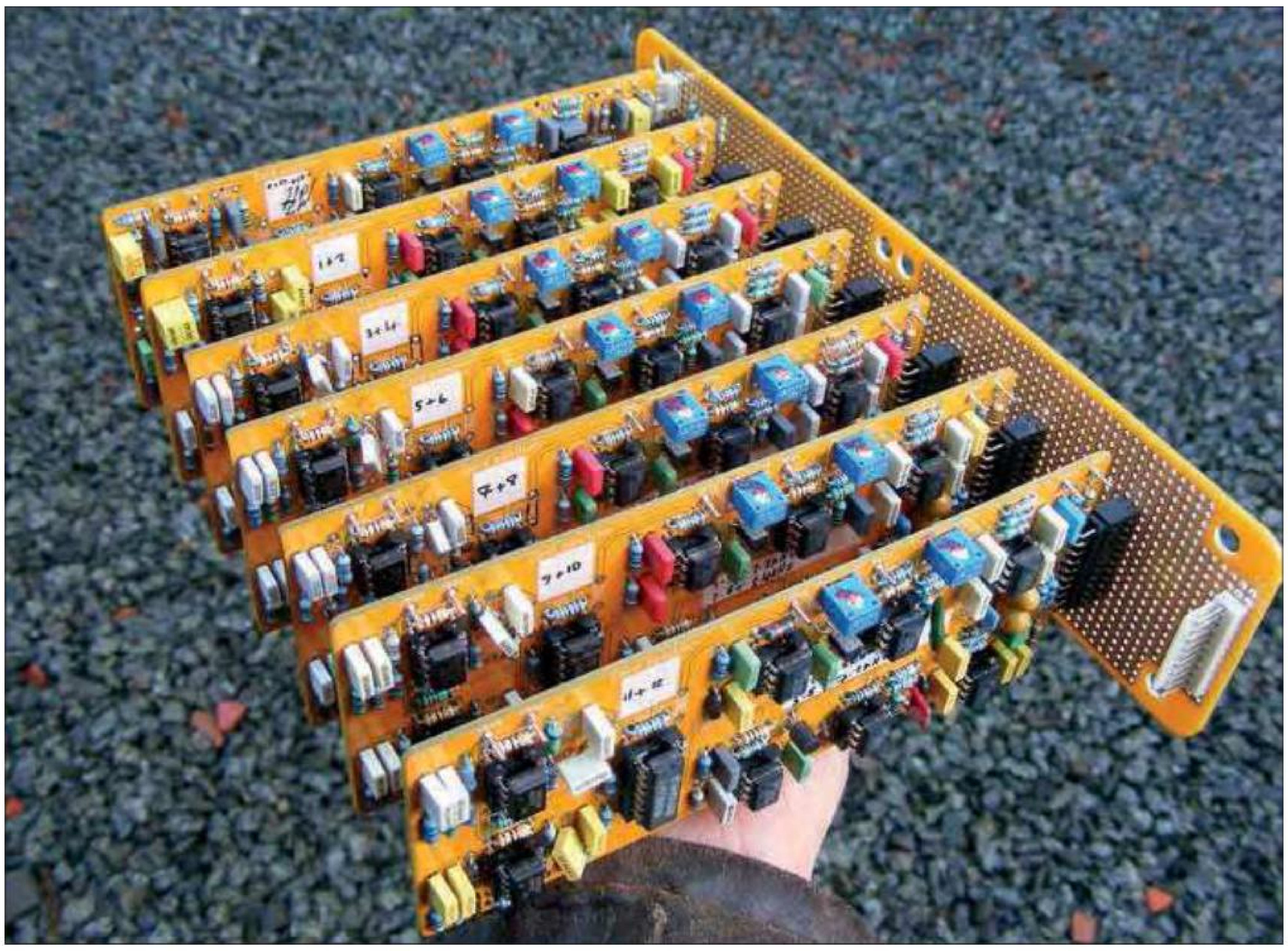


Fig.1. The heart of the vocoder with six band-pass filter cards and a high-pass/low-pass card. All plugged into the bus board. (No letters from lexicographical pedants please. It can be 'bus' or 'buss'! However, it's always 'busses'.)

This month, we get to the real nitty-gritty of the project – the filter cards, which are the heart of the *Analogue Vocoder*. Getting all the many parts together and soldering-up will take a long time, so you really need to pay attention! There are six band-pass cards, each containing two channels. There is also a single card containing a high-pass channel and a low-pass channel called the 'HP/LP board'. These all plug into a bus board with common busses for power, two audio inputs and the two audio summing lines. These boards are unique to the *Analogue Vocoder*, they're not generic audio boards like the previous mic pre-amp and driver boards. This assembly is shown in Fig.1.

Jelly bean circuits

The full circuit of a band-pass card is shown in Fig.2. Take care with the dual-channel annotation. Luckily, it's just a large number of 'Jellybean' parts, no weird expensive components. Note there are a few improvements (differences!) compared to the previous channel circuit given in the December 2021 issue. First, R24 should be 180Ω and the decoupling capacitors C14, C15 and C16 have been re-numbered in a different order. Ceramic rail-to-rail decoupling capacitor C16 has become C30 because I had to move it to the other end of the board where the NE5532 output chips were. This was necessary because 5532s are fussier about supply decoupling than TL082s. And another minor detail, the buffer around IC3a got its input pins mixed up – Fig.2 here is the correct version.

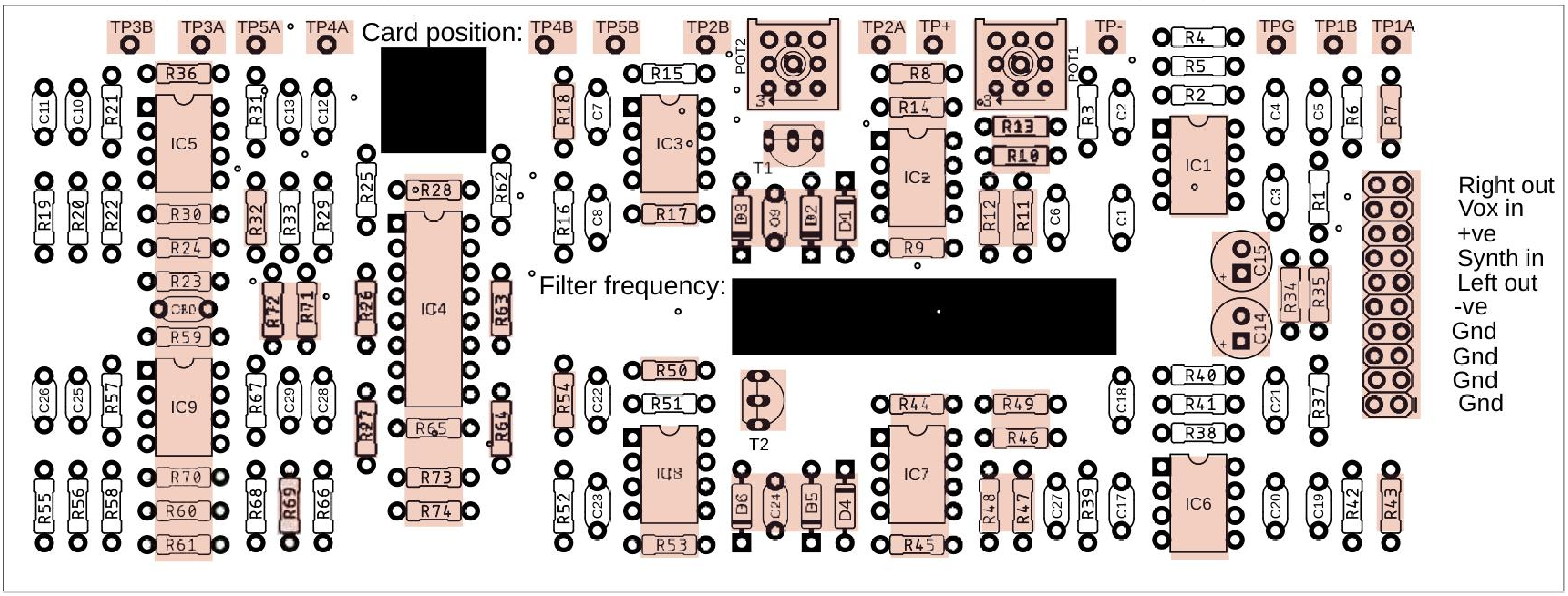
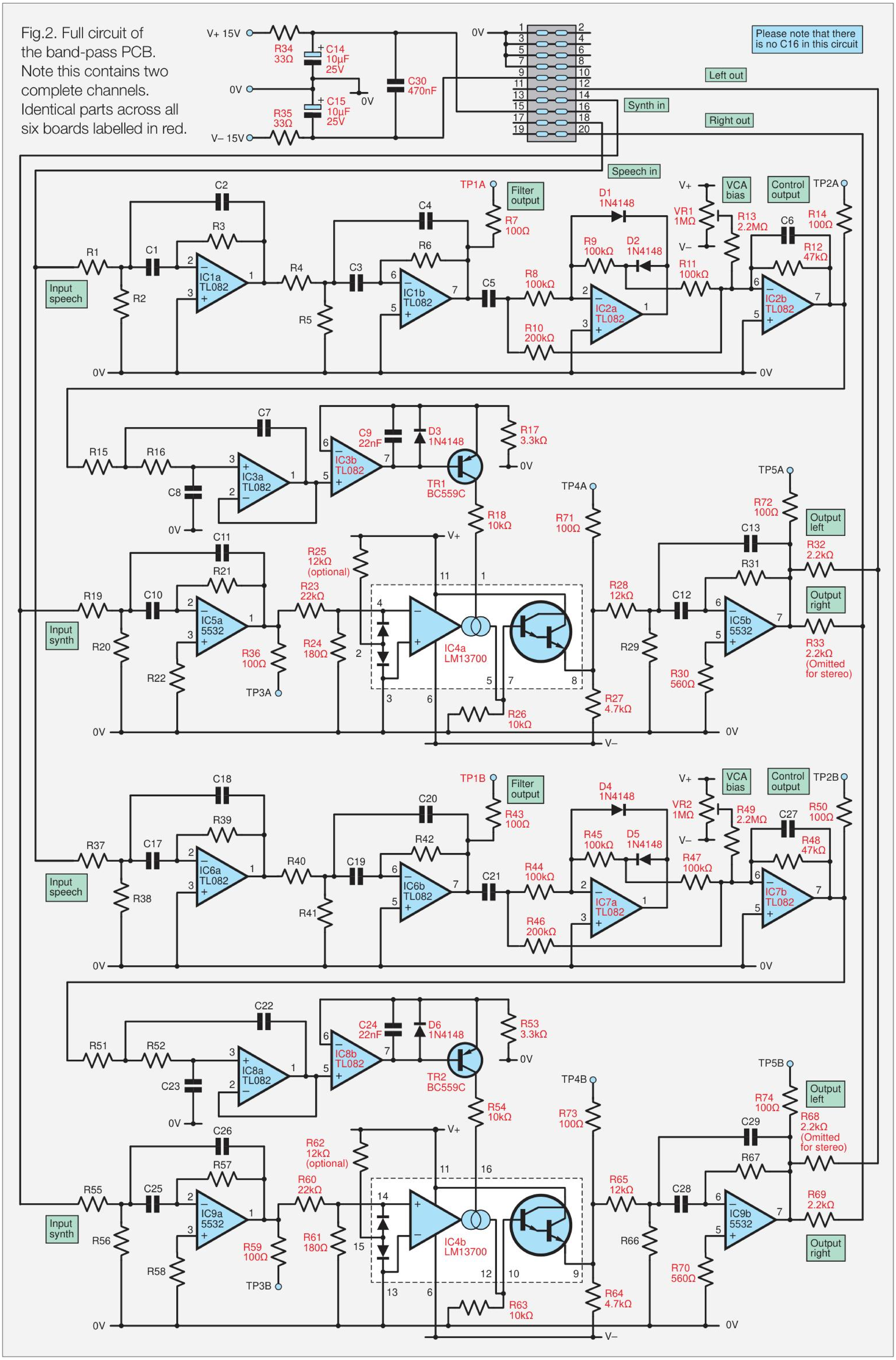

TP3B
TP3A
TP5A
TP4A
Card position:
TP4B
TP5B
TP2B
TP2A
TP+
TP-
TPG
TP1B
TP1A
POT2
POT1
R36
R15
R8
R4
R5
R14
R2
R13
R10
C11
C10
R21
R31
C13
C12
R18
C7
C2
C4
C5
R6
R7
R3
IC5
IC3
IC2
IC1
T1
R19
R20
R22
R30
R32
R33
R29
R25
R28
R62
R16
C8
R17
D3
C9
D2
D1
R12
R11
C6
C1
C3
R1
R24
R9
R23
C30
R72
R71
R26
IC4
R63
Filter frequency:
C15
C14
R34
R35
R59
Right out
Vox in
+ve
Synth in
Left out
-ve
Gnd
Gnd
Gnd
Gnd
C26
C25
R57
IC9
R67
C29
C28
R27
R65
R64
R54
C22
R50
R51
T2
R44
R49
R46
C18
R40
R41
R38
C21
R37
R55
R56
R58
R70
R60
R61
R68
R69
R66
R73
R74
R52
C23
IC8
R53
D6
C24
D5
D4
IC7
R45
R48
R47
C27
R39
C17
IC6
C20
C19
R42
R43

Fig.3. Band-pass filter card overlay showing common components highlighted in red. (PCB design by Mike Grindle)

Fig.2. Full circuit of the band-pass PCB. Note this contains two complete channels. Identical parts across all six boards labelled in red.


V+ 15V
R34
33Ω
C14
10µF
25V
0V
C15
10µF
25V
R35
33Ω
V– 15V
C30
470nF
0V
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Please note that there is no C16 in this circuit
Left out
Synth in
Right out
Speech in
C2
R3
R1
C1
R2
IC1a
TL082
Input speech
R4
C3
R5
C4
R6
IC1b
TL082
TP1A
Filter output
R7
100Ω
C5
R8
100kΩ
R10
200kΩ
D1
1N4148
R9
100kΩ
D2
1N4148
IC2a
TL082
V+
V–
VR1
1MΩ
VCA bias
R13
2.2MΩ
R11
100kΩ
Control output
TP2A
C6
R14
100Ω
R12
47kΩ
IC2b
TL082
0V
C7
R15
R16
C8
IC3a
TL082
C9
22nF
IC3b
TL082
D3
1N4148
R17
3.3kΩ
TR1
BC559C
R18
10kΩ
TP4A
R71
100Ω
TP5A
R72
100Ω
Output left
C13
R32
2.2kΩ
R31
Output right
C11
R21
R19
C10
IC5a
5532
Input synth
R20
R22
R36
100Ω
TP3A
R25
12kΩ
(optional)
R23
22kΩ
R24
180Ω
IC4a
LM13700
R26
10kΩ
R27
4.7kΩ
R28
12kΩ
C12
R29
IC5b
5532
R30
560Ω
R33
2.2kΩ
(Omitted for stereo)
C18
R39
R37
C17
R38
IC6a
TL082
Input speech
R40
C19
R41
C20
R42
IC6b
TL082
TP1B
Filter output
R43
100Ω
C21
R44
100kΩ
R46
200kΩ
D4
1N4148
R45
100kΩ
D5
1N4148
IC7a
TL082
VR2
1MΩ
VCA bias
R49
2.2MΩ
R47
100kΩ
Control output
TP2B
C27
R50
100Ω
R48
47kΩ
IC7b
TL082
C22
R51
R52
C23
IC8a
TL082
C24
22nF
IC8b
TL082
D6
1N4148
R53
3.3kΩ
TR2
BC559C
R54
10kΩ
TP4B
R73
100Ω
TP5B
R74
100Ω
Output left
C29
R68
2.2kΩ
(Omitted for stereo)
R67
C26
R57
R55
C25
IC9a
5532
Input synth
R56
R58
R59
100Ω
TP3B
R62
12kΩ
(optional)
R60
22kΩ
R61
180Ω
IC4b
LM13700
R63
10kΩ
R64
4.7kΩ
R65
12kΩ
C28
R66
IC9b
5532
R70
560Ω
R69
2.2kΩ
Output right

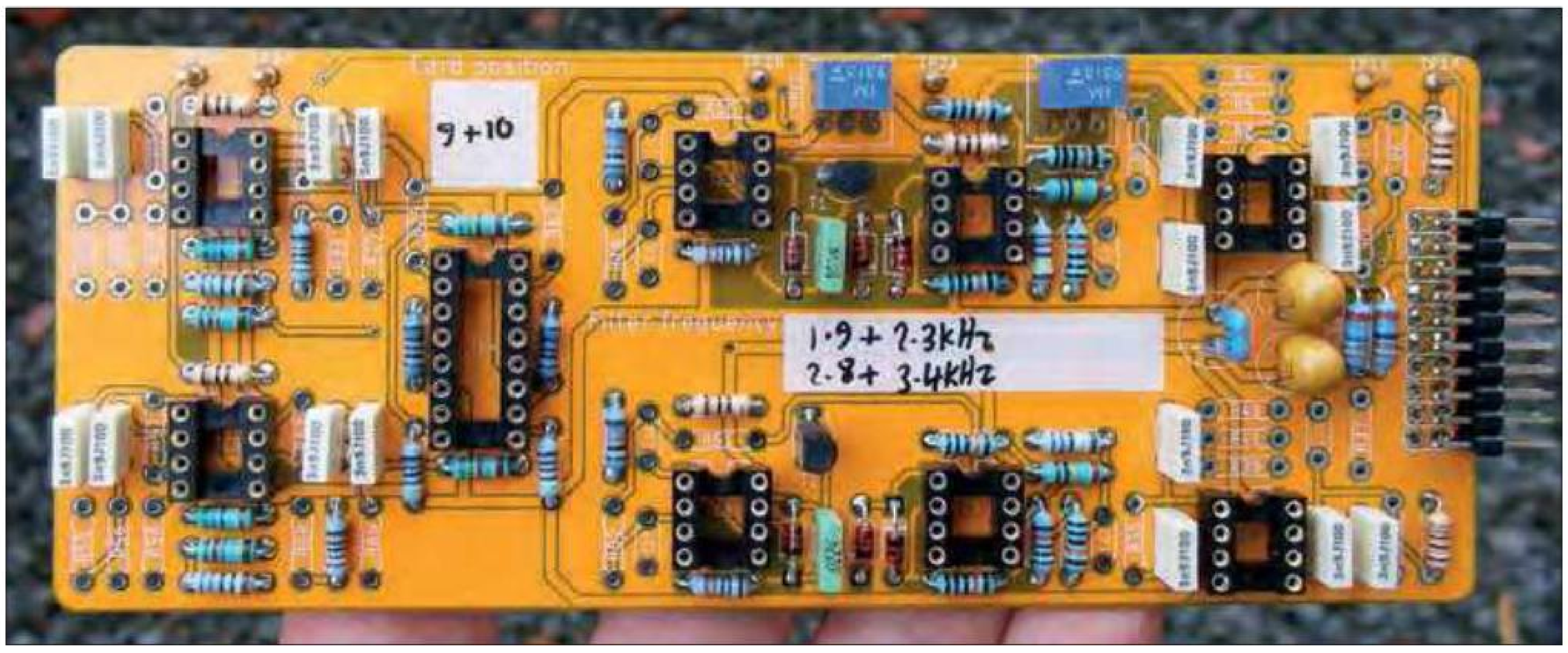


Fig.4. Photo of band-pass board showing common components inserted. Note the white 3.9nF capacitors are the filter capacitors. Note the white silkscreen label areas.

The second major change is that I've phase reversed every other channel by flipping the inverting and non-inverting pins on the transconductance op amp IC4b. This gives less phase cancellation in the frequency response overlap regions of the filters. When mixed together in mono a clearer sound is produced. Normally, an extra inverting op amp stage is used to do this, such as in the vocoder design by Richard Becker (*ETI*, September 1980). When I realised it wasn't necessary it seemed silly not to do the mod.

Getting stuffed

On all seven filter boards (HP/LP and bandpass) the VCA and full-wave rectifier components are identical in all the filter channels, so when populating the boards it's best to fit these first, as listed immediately below. The overlay for common components is shown in Fig.3 with a photo in Fig.4. I do a run like this of six band-pass boards. The HP/LP board also has these components.

Then I add the eight main filter capacitors to the band-pass boards, where there are four values covering all the frequencies. Most are 33nF. Finally, the remaining components are installed which are unique to each filter frequency and the HP/LP board. These component values are given in Table 1. Mike Grindle, my PCB man, had the great idea of placing white areas on the silk screen for writing the frequencies. *You must label the boards before building!*

Components – bandpass

The following parts are common to all six bandpass boards. Frequency-specific parts for the bandpass boards are not listed, but are given in Table 1. (The parts in Table 1 are 1% 0.25W metal film resistors, and 5% (preferred) or 10% 5mm plastic film capacitors.)

Band-pass channel and frequency		R2, 5, 20, 29 R38, 41, 56, 66 (kΩ)	R1, 19 R37, 55 (kΩ)	R3, 21, 22 R39, 57, 58 (kΩ)	C1, 2, 3, 4, 10, 11, 12, 13 C17, 18, 19, 20, 25, 26, 28, 29 (nF)	R4 R40 (kΩ)	R6, 31 R42, R67 (kΩ)	C5 C21 (nF)	C6 C27 (nF)	C7 C22 (nF)	C8 C23 (nF)	R15, 16 R51, R52 (kΩ)
Ch	**Freq (Hz)**											
1	86 / 125	0.22	1.6	56	330	12	68	100	330	100	22	390
2	135 / 60	1.5	15	390	33	75	470	68	220	68	15	390
3	190 / 230	1.0	13	270	33	56	330	47	150	47	10	390
4	280 / 340	0.68	5.1	180	33	39	220	33	100	330	68	82
5	420 / 500	0.47	3.6	120	33	27	150	22	82	220	47	82
6	580 / 720	0.33	2.4	82	33	18	100	15	56	150	33	82
7	860 / 1250	0.27	1.6	56	33	12	68	10	39	100	22	82
8	1350 / 1600	0.15	1.1	39	33	8.2	47	6.8	22	68	15	82
9	1900 / 2300	1.0	7.5	270	3.9	56	330	4.7	18	47	10	82
10	2800 / 3400	0.68	5.1	180	3.9	39	220	3.3	12	33	6.8	82
11	4200 / 5000	0.47	3.6	120	3.9	27	150	2.2	8.2	22	4.7	82
12	5800 / 7200	0.33	2.4	82	4.7	18	100	1.5	5.6	15	3.3	82

Table 1. Frequency-specific components for band-pass filters.

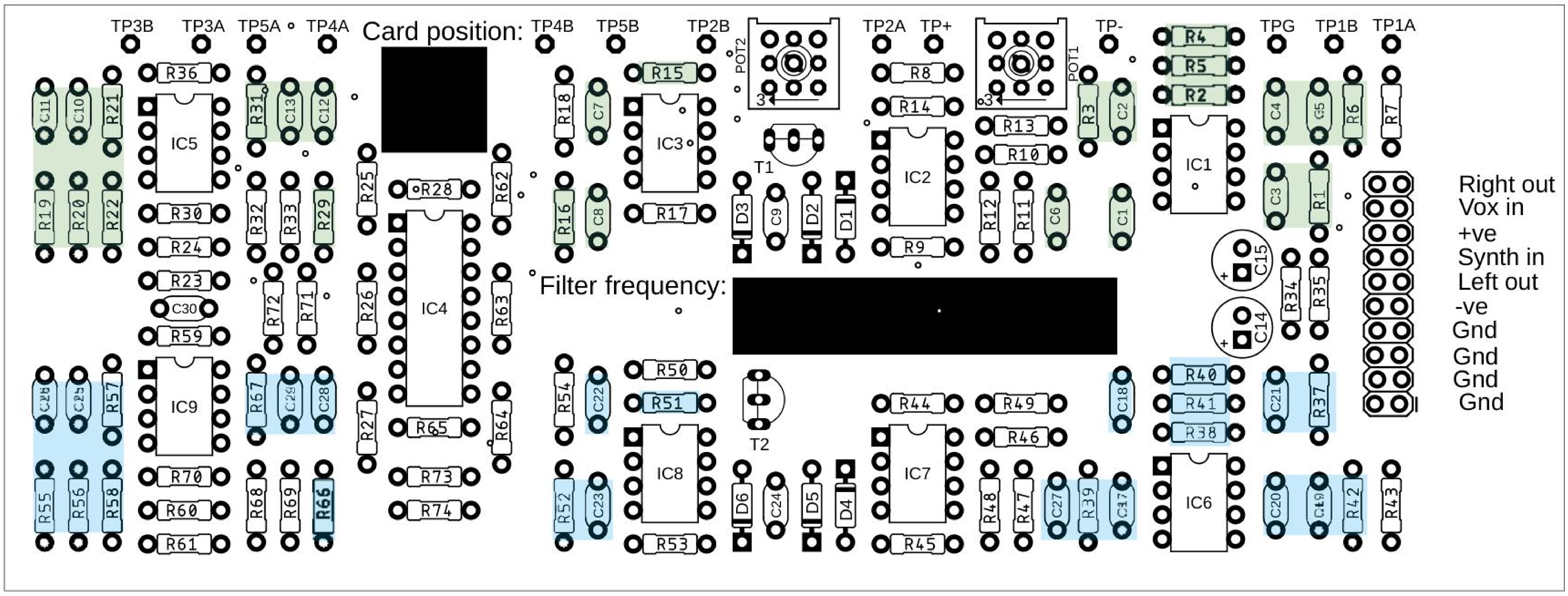


Fig.5. Overlay of band-pass board, frequency-specific parts highlighted – green odd channels, blue for even. (PCB design by Mike Grindle)

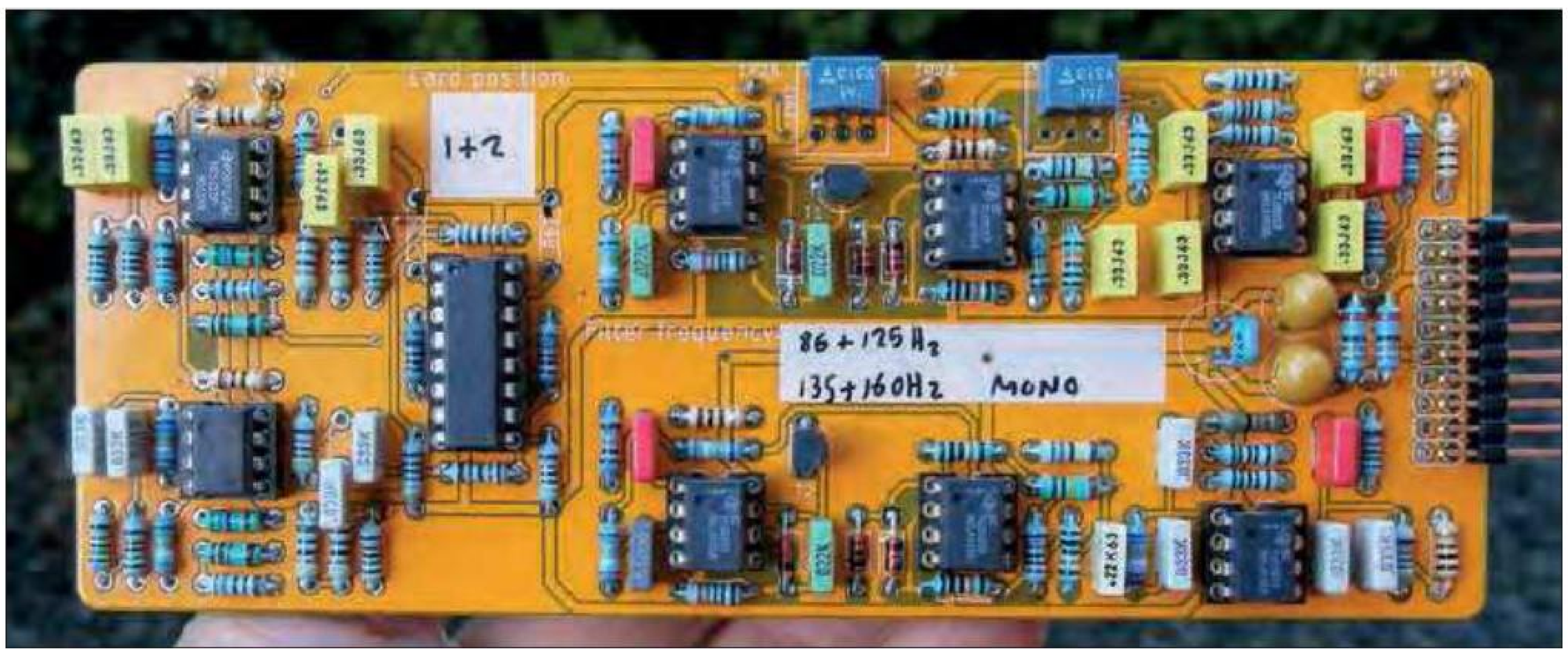


Fig.6. Completed band-pass board (note that since this prototype was made, a couple of capacitors have been repositioned).

The quantities listed are for one bandpass board – you need to multiply quantities by the number of boards used, normally six. All parts available from author (see AOShop ad on page 53).

Semiconductors

IC1-IC3, IC6-IC8	TL082 JFET input dual op amp or equivalent (eg LF353 or TL072)
IC4	LM13700 dual transconductance op amp
IC5, IC9	NE5532 low-noise dual op amp or equivalent, such as LM833
TR1, TR2	BC559C small-signal PNP (can be any general-purpose centre-base pin-out – eg, BC212)
D1-D6	1N4148

Resistors

All 1% 0.25W metal-film

R8, R9, R11, R19	100kΩ
R10, R46	200kΩ
R7, R14, R36, R43, R50, R59, R71-R74	100Ω (10 off)
R13, R49	2.2MΩ
R12, R48	47kΩ
R17, R53	3.3kΩ
R18, R54	10kΩ
R23, R60	22kΩ
R24, R61	180Ω
R26, R63	10kΩ
R25, R28, R62, R65	12kΩ (R25 and R62 not normally used), R24 and R65 have to be reduced to compensate.
R30, R70	560Ω
R34, R35	33Ω
R32, R33, R68, R69	2.2kΩ (see Stereo panning below, 4.7kΩ for mono channels)
VR1 and VR2	1MΩ Side adjust/vertical trimmer 0.1-inch or TO5 spacing.

Capacitors

C9, C24	22nF 20% 5mm ceramic/plastic film
C14, C15	10µF 25V tantalum bead or radial electrolytic
C30	470nF 20% X7R ceramic

Miscellaneous

Terminal pins	0.1-inch single-sided 8 off.
IC sockets	8-pin DIL 8 off.
PCB plug	male right-angle header 10+10 rows, Rapid part no. 22-0815, TruConnect. (Alternative: Tayda part no. 3420)

Also, 7 off female straight 10+10 pin double row header sockets for the bus board are required. Rapid part no. 22-5140. Manufacturer, Oupiin 2044-2*10G00SA. Tayda alternative 1690.

Freaky filter values

The filter frequencies for each channel are different, so most of the components associated with these have different values. Be careful here to avoid errors, which can be difficult to detect unless you can measure frequency response. Because the vocoder is effectively a parallel processor, it can work deceptively well with a few filter channels missing so it can be difficult to detect errors by listening. These filter values comprised one of the most tedious component lists I've ever typed, so I had to resort to a spreadsheet, as shown in Table 1. You can download the table from the March 2022 page of the *PE* website.

The next construction stage is to put in the filter components shown in the overlay in Fig.5 (it's quite crowded, but you can download it and Fig.8 to view/print them magnified from the March 2022 page of the *PE* website). Fig.6 shows a completed board.

High-pass / low-pass board

The common components and circuitry is the same as the band-pass channels, but the topology of the high-pass and low-pass filters is different, it's composed of standard cascaded Sallen and Key second-order sections, rather than multiple-feedback band-pass. The circuit for the LP/HP board is shown in Fig.7. the overlay in Fig.8 and a photo of the completed board in Fig.9.

Component list for HP/LP board

Semiconductors

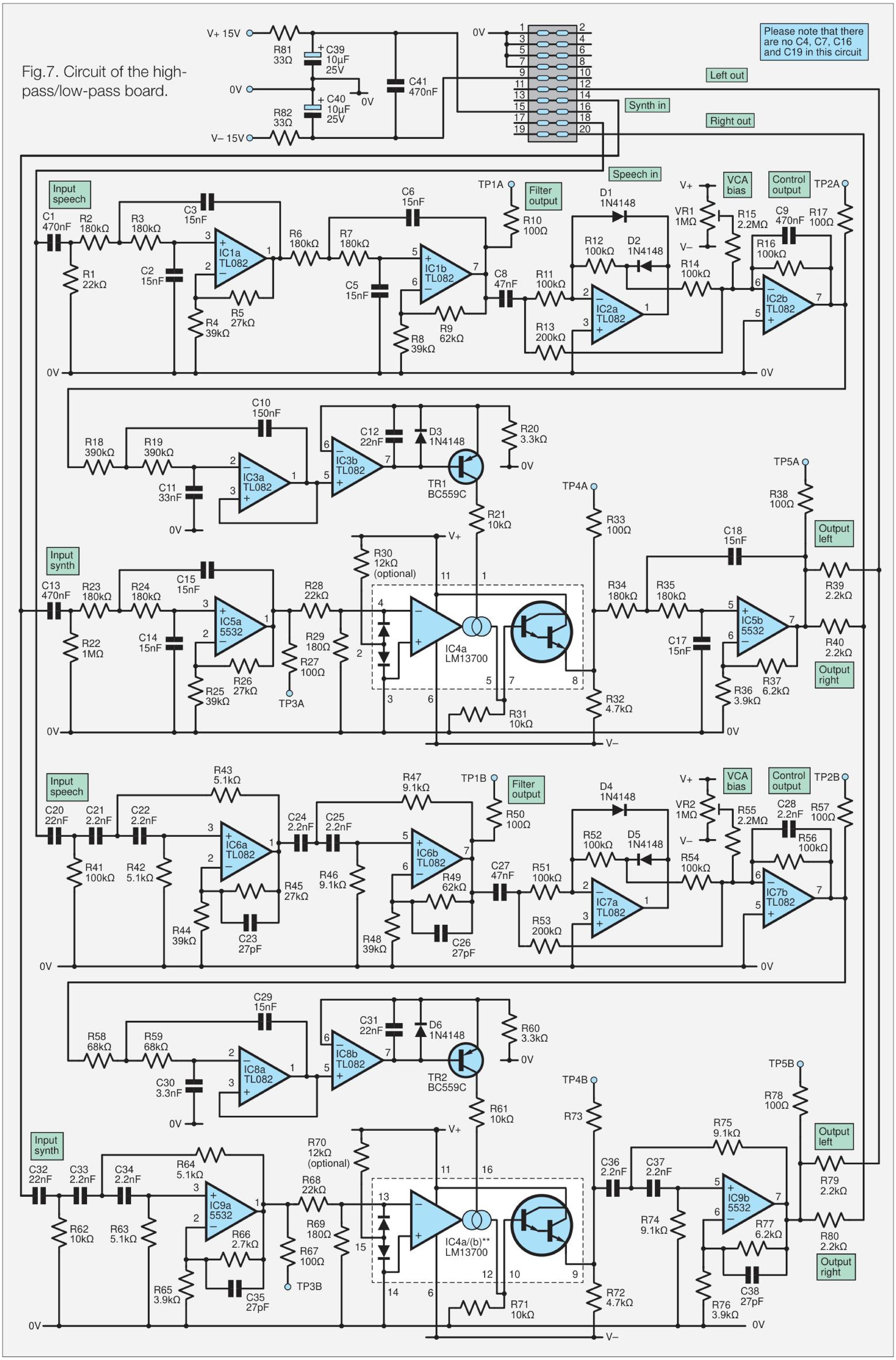
IC1-IC3, IC6-IC8	TL082 JFET input dual op amp or equivalent (eg LF353 or TL072)
IC4	LM13700 dual transconductance op amp
IC5, IC9	NE5532 low-noise dual op amp or equivalent, such as LM833
TR1, TR2	BC559 small-signal PNP (can be any general-purpose centre-base pin-out – eg, BC212)
D1-D3	1N4148

Capacitors

All are 5mm plastic-film 5% (preferred) or 10%, unless indicated with a '*'.

C1, C8, C9, C13	470nF
C8, C27	47nF
C2, C3, C5, C6, C14, C15, C17, C18, C29	15nF (9 off)
C10	150nF
C11	33nF
C12, C20, C31, C32	22nF 20% ceramic or plastic-film*
C30	3.3nF
C21, C22, C24, C25, C28, C33, C34, C36, C37	2.2nF (9 off)
C23, C26, C35, C38	27pF ceramic
C39, C40	10µF 25V tantalum or electrolytic*
C41	470nF 20% ceramic X7R*

Fig.7. Circuit of the high-pass/low-pass board.


Please note that there are no C4, C7, C16 and C19 in this circuit
V+ 15V
R81 33Ω
C39 10µF 25V
0V
C40 10µF 25V
R82 33Ω
V– 15V
C41 470nF
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Left out
Synth in
Right out
Speech in
Input speech
C1 470nF
R1 22kΩ
R2 180kΩ
R3 180kΩ
C2 15nF
C3 15nF
IC1a TL082
R4 39kΩ
R5 27kΩ
R6 180kΩ
R7 180kΩ
C5 15nF
C6 15nF
IC1b TL082
R8 39kΩ
R9 62kΩ
TP1A
Filter output
R10 100Ω
C8 47nF
R11 100kΩ
R13 200kΩ
IC2a TL082
D1 1N4148
R12 100kΩ
D2 1N4148
R14 100kΩ
V+
VCA bias
VR1 1MΩ
V–
R15 2.2MΩ
Control output
C9 470nF
R16 100kΩ
R17 100Ω
TP2A
IC2b TL082
R18 390kΩ
R19 390kΩ
C10 150nF
C11 33nF
IC3a TL082
C12 22nF
IC3b TL082
D3 1N4148
TR1 BC559C
R20 3.3kΩ
R21 10kΩ
TP4A
R33 100Ω
TP5A
R38 100Ω
Input synth
C13 470nF
R22 1MΩ
R23 180kΩ
R24 180kΩ
C14 15nF
C15 15nF
IC5a 5532
R25 39kΩ
R26 27kΩ
R27 100Ω
TP3A
R28 22kΩ
R29 180Ω
R30 12kΩ (optional)
IC4a LM13700
R31 10kΩ
R32 4.7kΩ
R34 180kΩ
R35 180kΩ
C17 15nF
C18 15nF
IC5b 5532
R36 3.9kΩ
R37 6.2kΩ
R39 2.2kΩ
R40 2.2kΩ
Output left
Output right
C20 22nF
C21 2.2nF
C22 2.2nF
R41 100kΩ
R42 5.1kΩ
R43 5.1kΩ
IC6a TL082
R44 39kΩ
R45 27kΩ
C23 27pF
C24 2.2nF
C25 2.2nF
R46 9.1kΩ
R47 9.1kΩ
IC6b TL082
R48 39kΩ
R49 62kΩ
C26 27pF
TP1B
R50 100Ω
C27 47nF
R51 100kΩ
R53 200kΩ
IC7a TL082
D4 1N4148
R52 100kΩ
D5 1N4148
R54 100kΩ
VR2 1MΩ
R55 2.2MΩ
C28 2.2nF
R56 100kΩ
R57 100Ω
TP2B
IC7b TL082
R58 68kΩ
R59 68kΩ
C29 15nF
C30 3.3nF
IC8a TL082
C31 22nF
IC8b TL082
D6 1N4148
TR2 BC559C
R60 3.3kΩ
R61 10kΩ
TP4B
R73
TP5B
R78 100Ω
C32 22nF
C33 2.2nF
C34 2.2nF
R62 10kΩ
R63 5.1kΩ
R64 5.1kΩ
IC9a 5532
R65 3.9kΩ
R66 2.7kΩ
C35 27pF
R67 100Ω
TP3B
R68 22kΩ
R69 180Ω
R70 12kΩ (optional)
IC4a/(b)** LM13700
R71 10kΩ
R72 4.7kΩ
C36 2.2nF
C37 2.2nF
R74 9.1kΩ
R75 9.1kΩ
IC9b 5532
R76 3.9kΩ
R77 6.2kΩ
C38 27pF
R79 2.2kΩ
R80 2.2kΩ

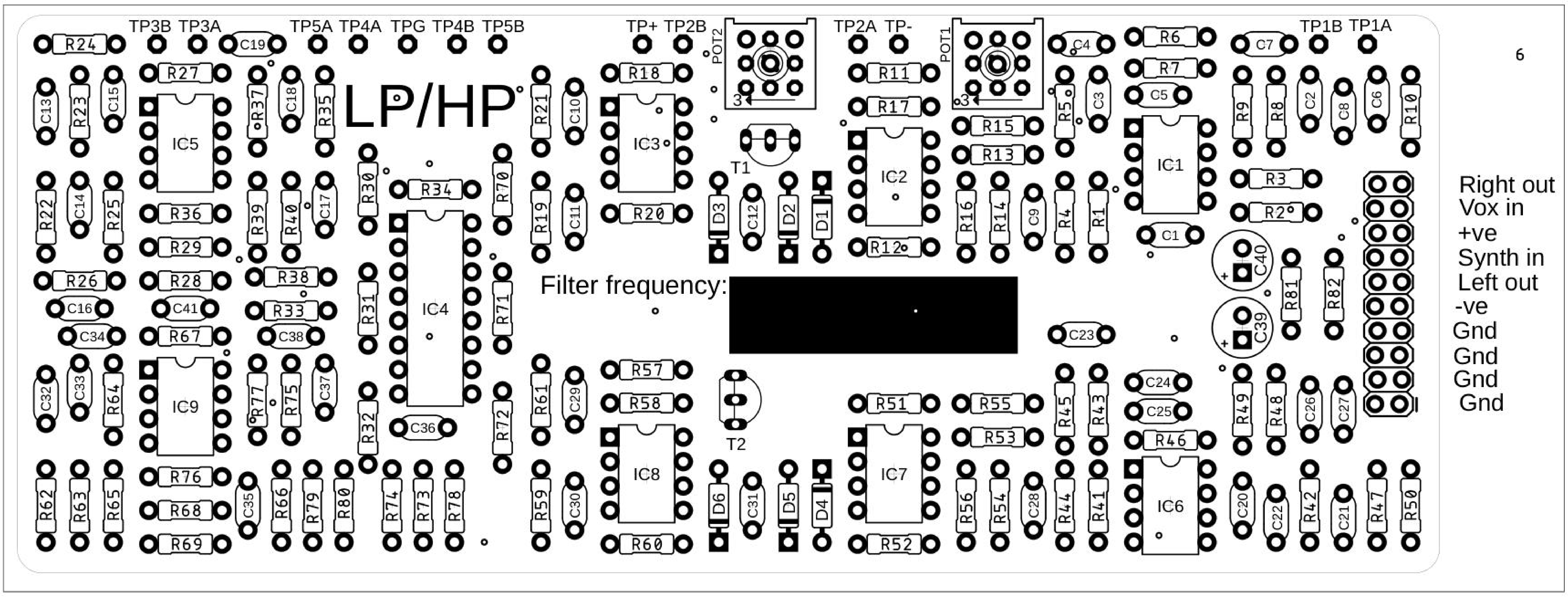


Fig.8. Component overlay of HP/LP board. (PCB design by Mike Grindle)

Resistors

All 0.25W 1% metal-film

R1, R22	1MΩ
R2, R3, R6, R7, R23, R24, R34, R35 (8 off)	180kΩ
R4, R8, R25, R44, R48	39kΩ
R5, R26, R45	27kΩ
R9, R49	62kΩ
R10, R17, R27, R33, R38, R50, R57, R67, R73, R78 (10 off)	100Ω
R11, R12, R14, R16, R51, R52, R54, R56, R41	100kΩ
R13, R53	200kΩ
R15, R55	2.2MΩ
R18, R19	390kΩ
R20, R60	3.3kΩ
R30, R70 (not usually used)	12kΩ
R21, R31, R61, R62, R63, R71	10kΩ
R32, R72	4.7kΩ
R28, R68	22kΩ
R29, R69	180Ω
R36, R65, R76	3.9kΩ
R37, R77	6.2kΩ
R39, R40, R79, R80	2.2kΩ
R42, R43, R63, R64	5.1kΩ
R46, R47, R74, R75	9.1kΩ
R58, R59	68kΩ
R66	2.7kΩ
R81, R82	33Ω
VR1 and VR2	1MΩ side-adjust/vertical trimmer 0.1-inch or TO5 spacing.

Tuning for smoke

The power-rail decoupling resistors (R34/R35, R81/R82) also provide protection and confine shorts to the card. Since there is a possibility of inadvertent short circuits during testing, these resistors should be mounted a few millimetres above the board (Fig.10). Burnt resistors cost a penny, a burnt PCB a lot more! On one PCB a small ball of solder got lodged between two pins under IC2's turned-pin chip socket connecting the negative rail to ground, (pin 3 to 4) and it took ages to find. It was the first time I've seen it (Fig.11).

Stereo panning

On the band-pass boards, two summing resistors for the left (R32 and R68) and right (R33 and R69) mix busses are provided for each filter channel. Normally only R32 and R69 are inserted. This flips the channels alternately to left and right mixing busses as shown in Fig.12. However, for the mono channels (the HP/LP board and both the channels on the lowest-frequency band-pass board), all four resistors are inserted. (For the HP/LP board these resistors are R39, R40, and R79 , R80).

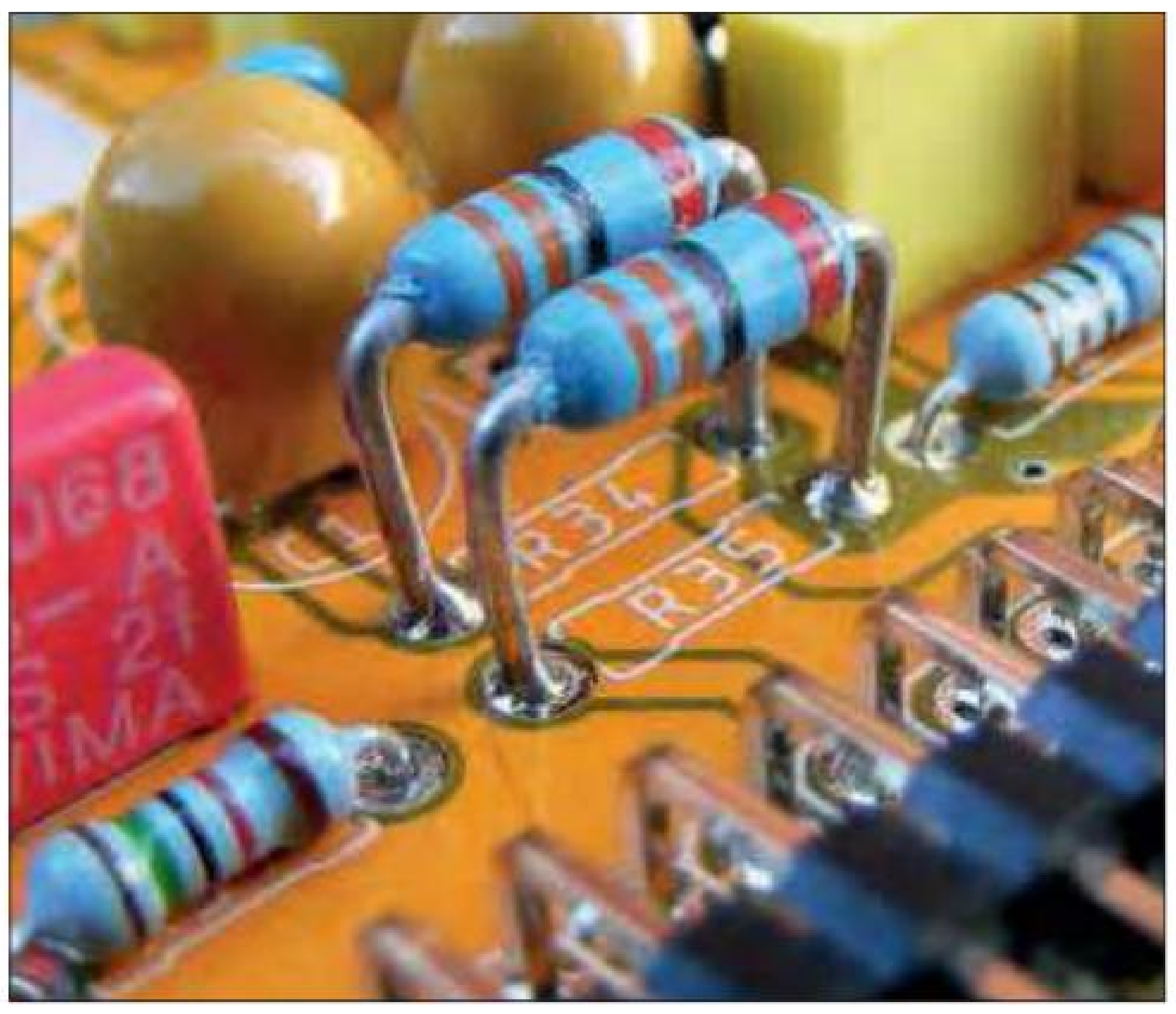


Fig.10. The power supply decoupling resistors R34 and R35 should be mounted off the board in case they get hot under fault conditions.

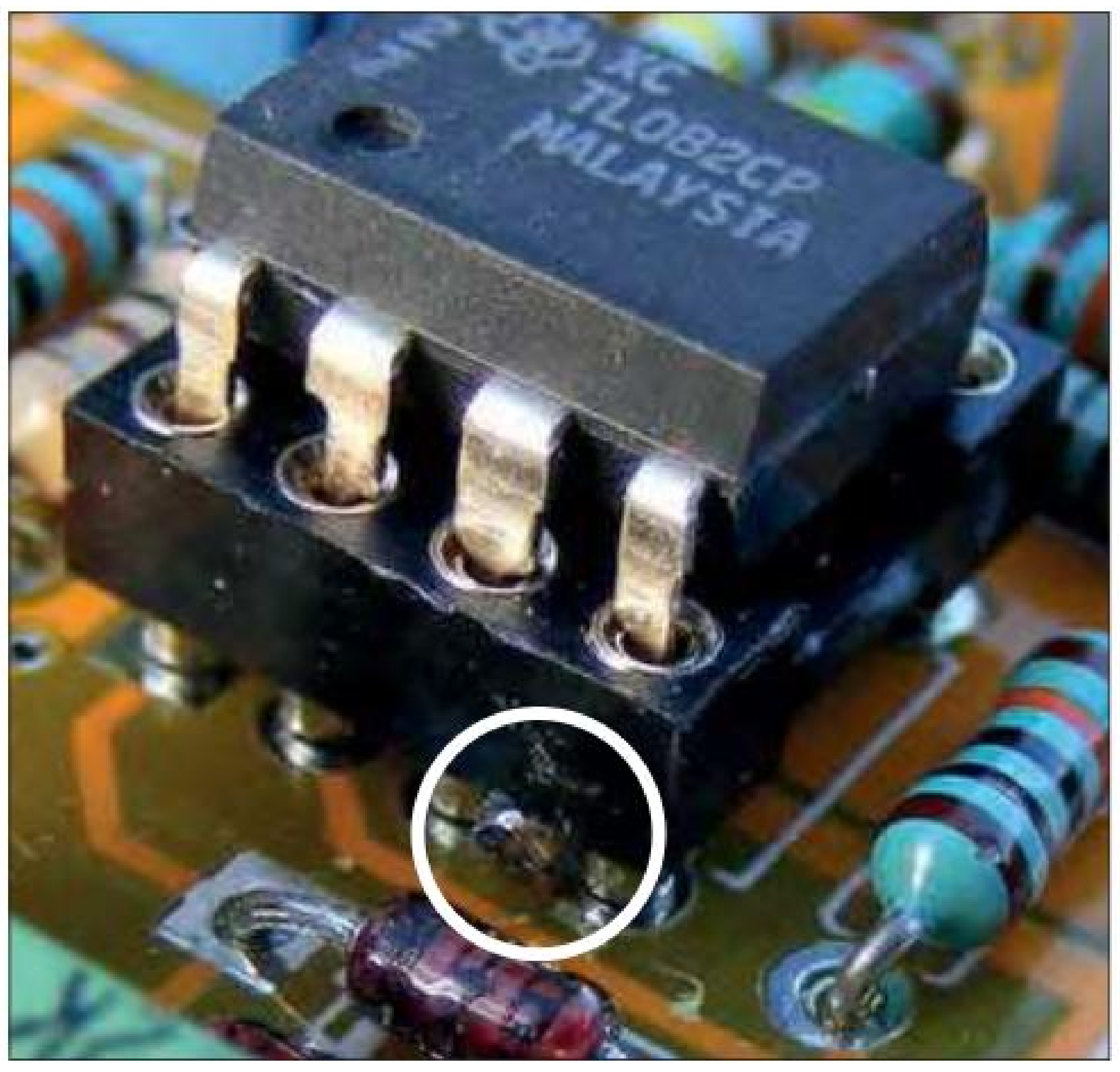


Fig.11. Short circuits can occur in the oddest places. This is a reconstruction of what occurred on one of my boards. In reality, it was worse, the solder ball was behind the pins so couldn't be seen and a Model 1000 Tracer had to be used to find it.

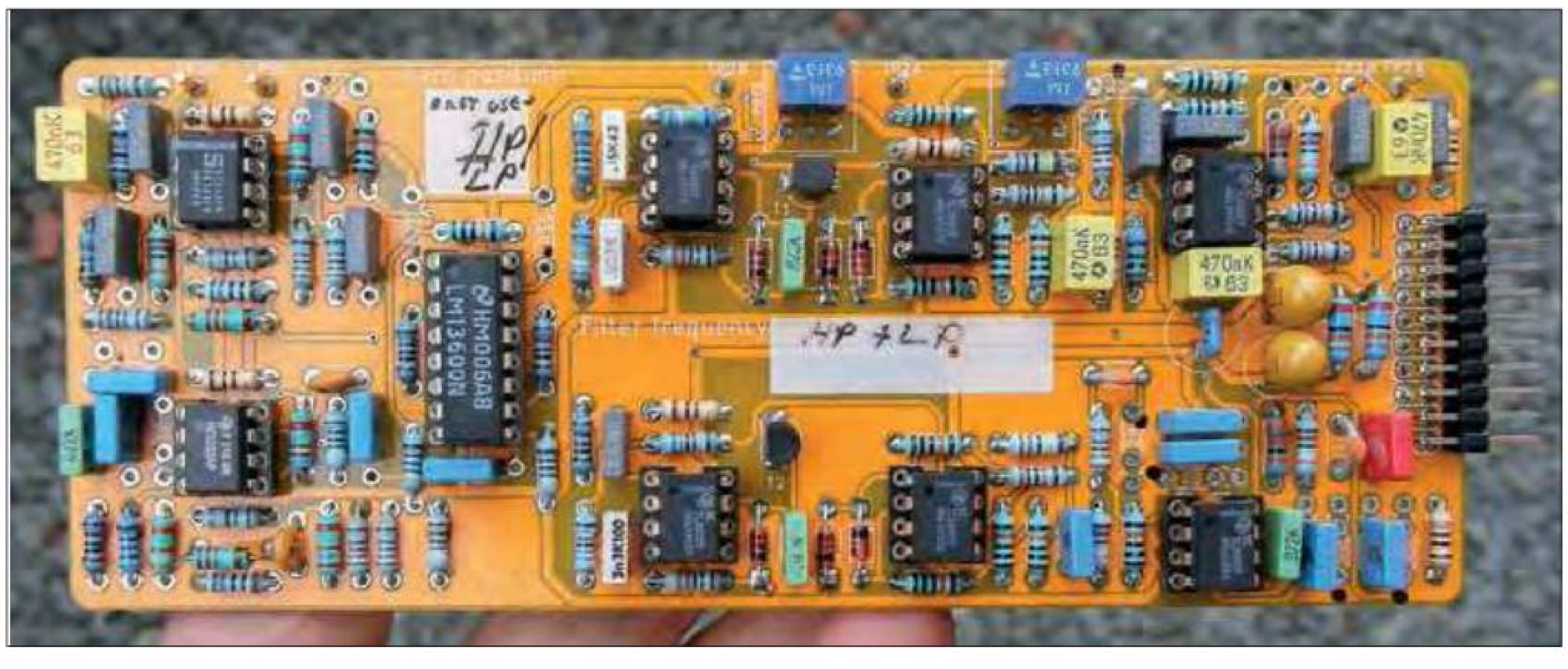
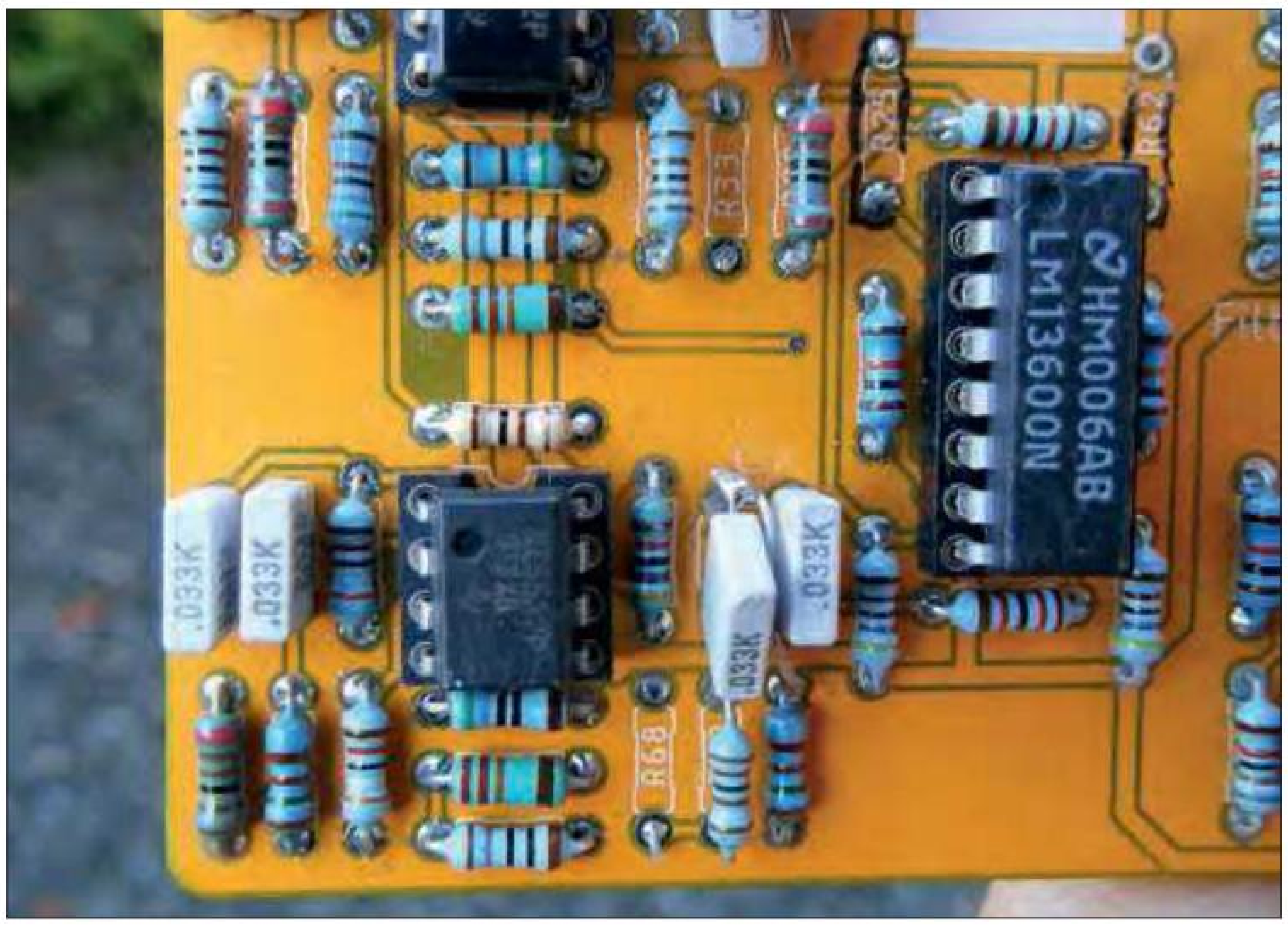


Fig.9. Completed HP/LP board. Note this was an earlier version with a few extra component positions for experimental purposes. All the boards supplied by *PE* will exactly conform to the overlays.



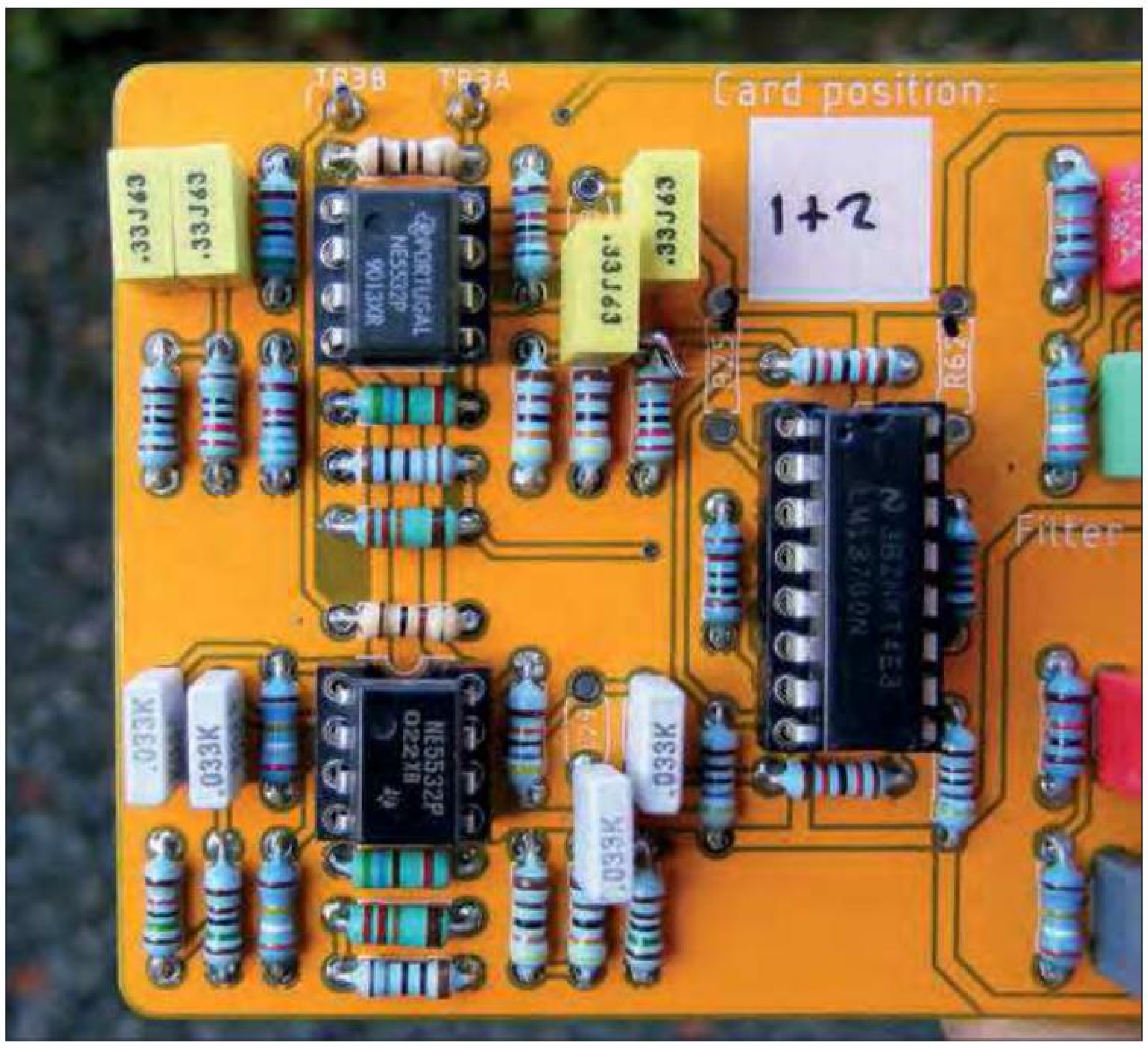


Fig.12. (above) To get a stereo effect, channels are panned alternately left and right by omitting resistors R33 and R68.
Fig.13. (Right) For mono channels, all four resistors are inserted and their value increased to 4.3kΩ.

In mono, to keep the relative levels the same on the band-pass board, the summing resistors are increased from 2.2kΩ to 4.3kΩ as implemented in Fig.13. Note that because the low-pass and high-pass filters have lower gain relative to the band-pass filters, their resistors are kept at 2.2kΩ.

Bus board

All the filter cards are plugged into a bus board, which is similar to a sophisticated Veroboard where the tracks don't come off. This is shown in Fig.14. Note how the connectors are double pin to reduce contact resistance and give increased mechanical stability (Fig.15). Extra connectors are also placed on this board to feed in the power and connect to the drive amplifier and mixer boards described last month. There are also additional pins to the summing busses for feeding in dry signals from the microphone and synthesiser if required.

Testing 1-2-3

As with all electronics, test in minimum-sized sections; get one channel card working at a time. If you connect the whole lot in one go, it's guaranteed not to work. First, do a basic visual check that all the polarised components such as the op amps are in the right way. Then, apply power to check for heating of R34 and R35 caused by excess current. Follow this with checks for DC offsets on the op amp test pins (TP1A/B) along the top of the board. 100Ω resistors are connected in series with the pins to stop oscillation when long test leads are connected. Now you're ready for the audio signal tests next month.

Trimming

Pricier vocoders (such as the Richard Becker design mentioned above) have typically five preset adjustments per channel. I reduced these to the absolute minimum of one for the VCA control voltage offset on each channel. VR1 and VR2 are trimmed to the point where the carrier signal (usually a string sound) is just backed off from breaking through. This point gives optimum linearity for best speech intelligibility.

The band-pass filters' Q can vary a lot with capacitor tolerances, since the multiple feedback band-pass filter equation assumes the two frequency determining capacitors are *exactly* equal. If cheap 10% types are used it is possible for their values to be up to 20% apart. When this happens, the resulting gain on individual channels can occasionally peak up excessively. If any frequencies dominate the output mix, the values of the filters' input resistors R1 and 19 or R37 and R55 can be increased. The levels here can be checked on test points TP1A and TP1B. If you want to add extra presets this is one area where it could be beneficial. Alternatively, one could use close-tolerance polystyrene capacitors. However, they may be difficult to mount on the boards vertically since they are often only available in axial form. An example is shown in Fig.16.

Next month

In the next article we'll cover the final construction and testing. Also, I'll present a triple-rail ultra-low-noise power supply suitable for the *Vocoder* and other audio systems, such as mixers, that use many op amps and/or require phantom power.

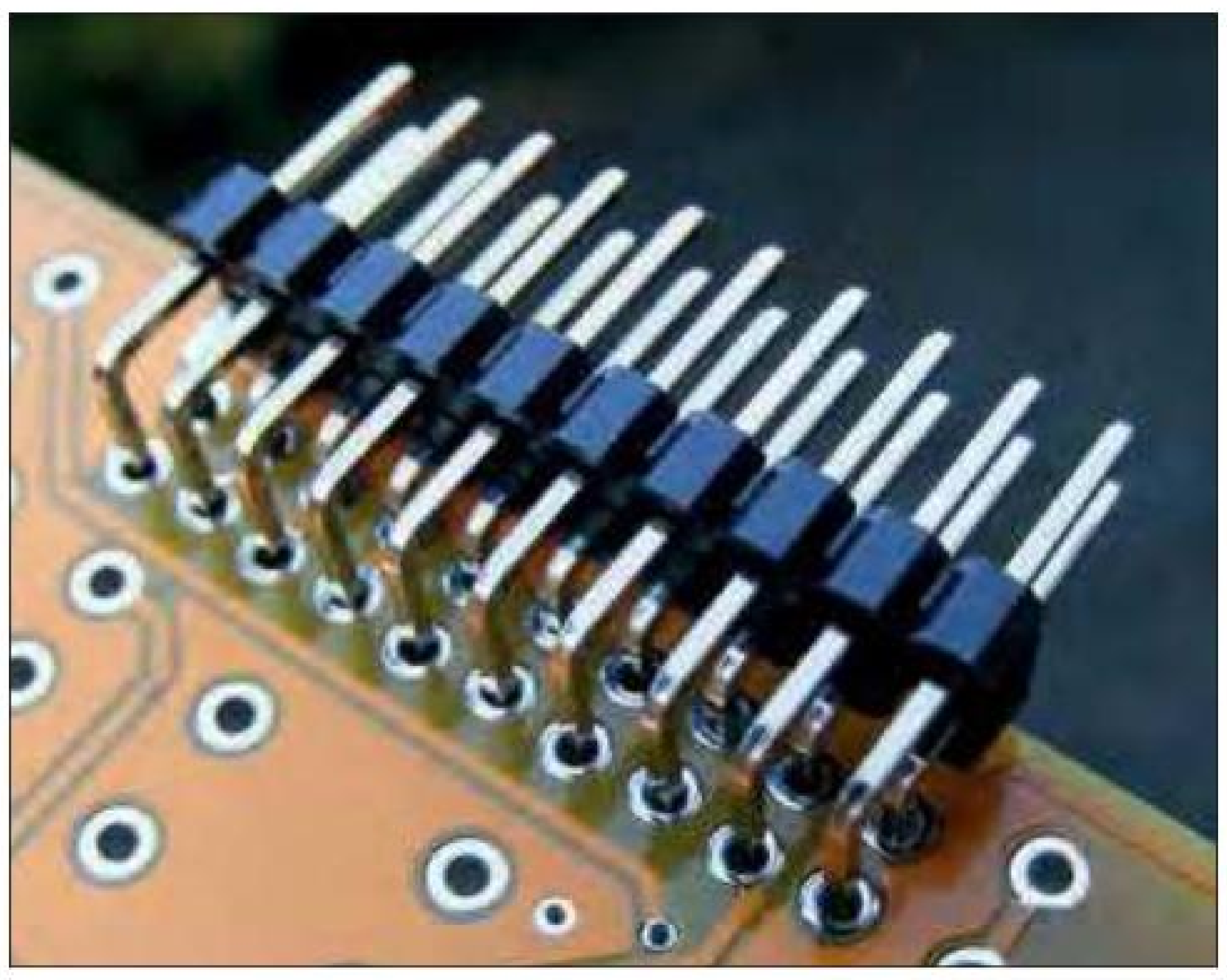


Fig.15. Connector plugs are doubled up to improve mechanical rigidity. Eight pins are used on the 0V rail for low impedance.

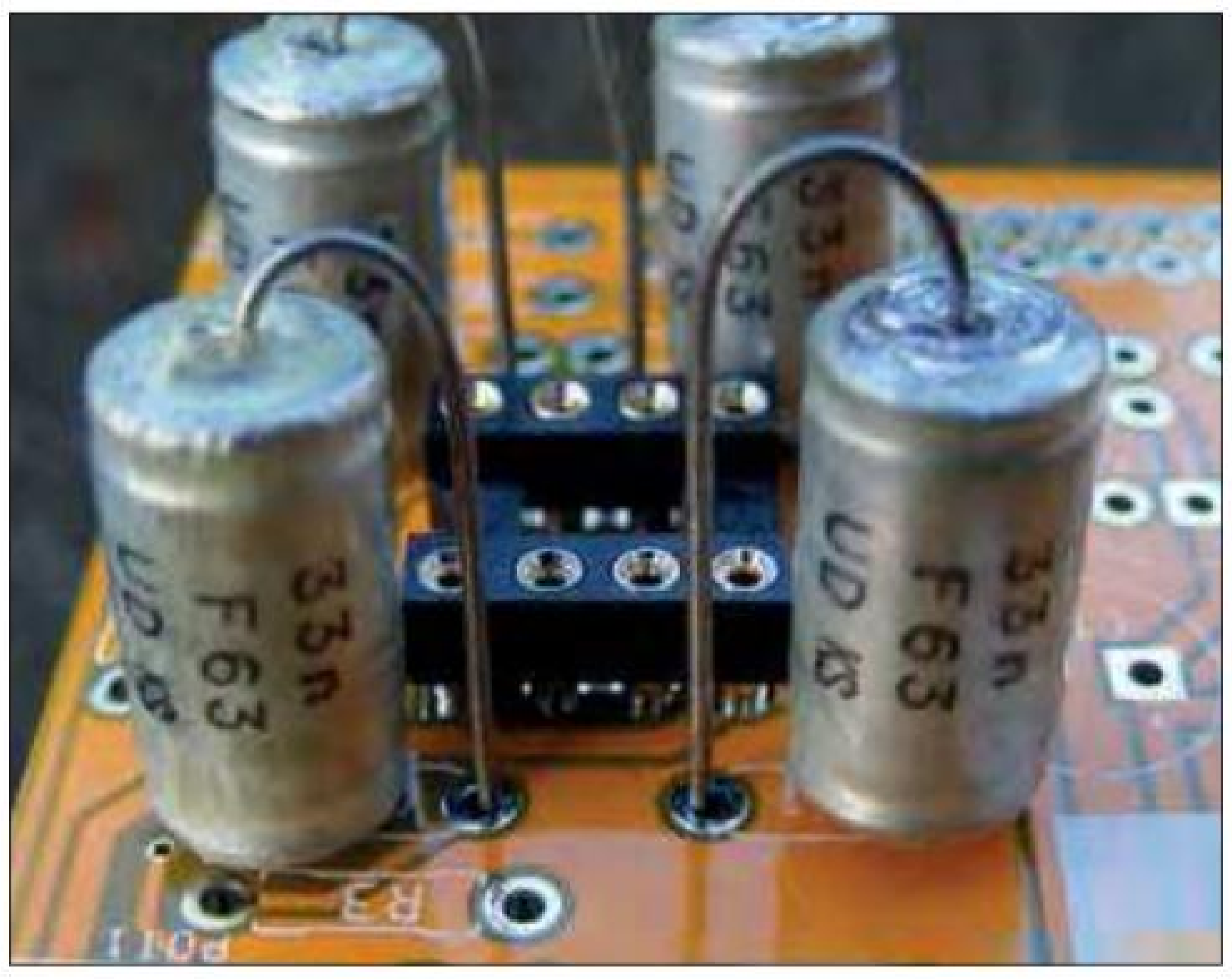


Fig.16. There is just about enough room to use 1% polystyrene capacitors for the filters, if you can get them. These Philips 424 series were excellent audio filter capacitors, but because the foil material was the neurotoxic metal lead, they were banned.

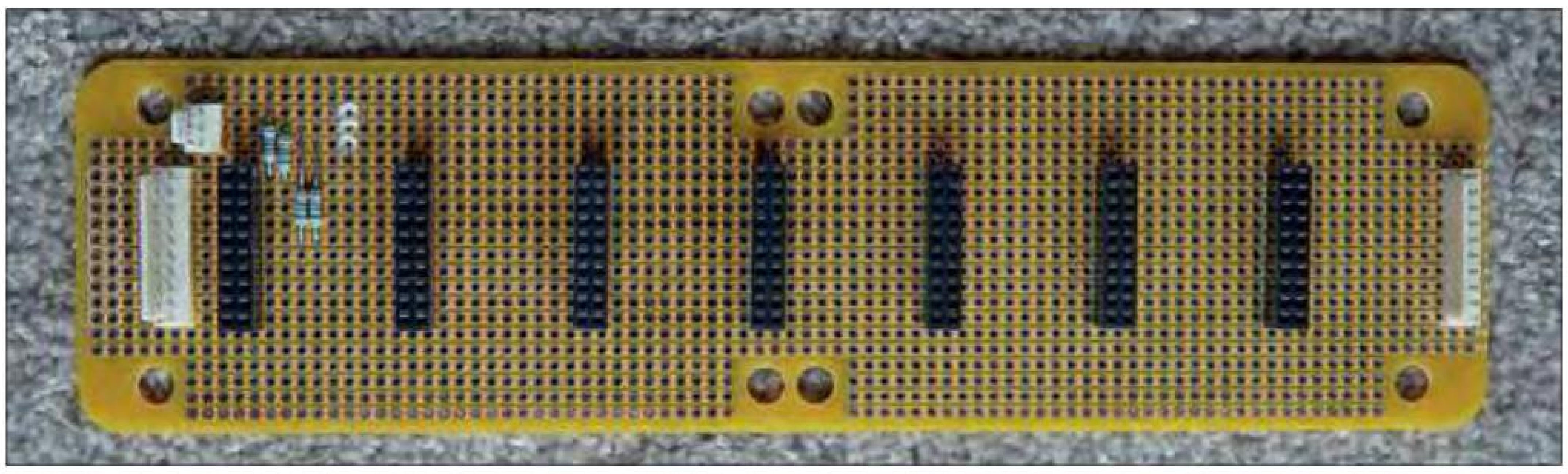


Fig.14. The bus board – note a few summing resistors have been added to allow for auxiliary inputs.

AOShop

The home for specialist audio, analogue and historic components – provided by Jake Rothman, *PE's Audio Out* columnist. The AOShop is your best bet for classic analogue 'NOS' (new old stock) components, including all parts for *Audio Out* projects and designs.

Ge semiconductors

Small-signal PNP transistors

AC125, NKT214F, OC57 OC59	**£1.00**

Low-noise PNP transistors

GET106	**£2.50**

Small power PNP transistors

AC153, AC153K, AC188	**£1.50**

High-voltage PNP transistors

OC77, CV7001, ACY20	**£1.50**

TO3 PNP power transistors

OC22, CV7054 (OC23), OC25, OC35, OC36, AD143, AD149, AD161, AD162	**£2.00**
AD140	**£3.50**
AD149 matched pair	**£5.00**

RF PNP transistors

OC41, OC42, 2SA12, 2SA53,AF124, AF128, GET872A	**£1.50**

NPN transistors

OC139, OC140, ASY73, AC141K, AC176K, AC176	**£2.00**

Diodes

CV7049 (OA10), CG92 (OA91)	**£0.50**

Si semiconductors

Diodes

ZC5800 RF Schottky	**£0.20**

Low-noise silicon transistors

BFW16A, 2SC3071	**£1.50**
2SC2204, 2SD655	**£0.50**
ZTX651	**£0.30**

RF transistors (suitable for Theremin)

BF199	**£0.50**
BF245	**£0.60**

Audio power MOSFETs

Exicon 10N20, 10P20	**£6.50**
Hitachi 2SJ99, 2SK343	**£3.50**
Hitachi 2SJ 50, 2SK135	**£7.00**
Hitachi 2SJ56, 2SK176	**£8.50**

JFETs

BFW11, BFW10, TIS73L, J177, J113, U1994, U1898, 2SJ176	**£1.00**

MOSFETs

ZVP2106A	**£0.30**
Dual-gate 3SK45, BFS28	**£1.50**

Metal-cased transistors

BC143	**£0.35**
2N1711	**£0.50**
BCY71	**£0.30**
BC109C	**£0.60**

Amplifiers

TL082 dual JFET input op amp	**£0.25**
LM318 high-speed op amp	**£0.35**
µA709 metal-cased op amp	**£2.00**
5534H metal-cased op amp	**£3.00**
LM384, TDA2030A	**£1.50**
TAA435 (power amp driver)	**£1.20**

Synthesiser ICs

That/dbx 2180 VCA/VCF	**£6.00**
CA3080 VCA/VCF (vocoder)	**£2.80**
CA3082 VCA/VCF	**£4.00**
LM13600/ LM13700 VCA/VCF	**£2.00**
CA3086 transistor array	**£1.00**
PT2399 echo/delay	**£1.50**

Dual transistors

2N2639, 2N2223, 2N2910 (NPN)	**£4.00**
E401 (JFET)	**£4.00**
DMMT3904/6	**£0.50**

Loudspeakers

PE Mini-Monitor

Volt PE165 6.5-inch woofer (each)	**£85**
Morel MDT29 tweeter (each)	**£25**
Kit *pair* of PE165/MDT29 plus Volt crossover parts and PCBs	**£299**
Monacor DT-28N tweeter (each)	**£45**
Vifa 19mm BC20SC15-04 tweeter (each)	**£15**
Volt PE110 5-inch woofer (each)	**£75**

Volt crossover inductors

1.2mH, 1.5mH, 2mH, 2.7mH, 0.5mH (tapped at 0.3mH) (each)	**£5.85**
LS3/5A transformer-core 15Ω assembled crossover board (each)	**£60**

Fully assembled and tested high-quality speaker prototypes – ask for details

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Note '10/63' denotes '10µF 63V'.

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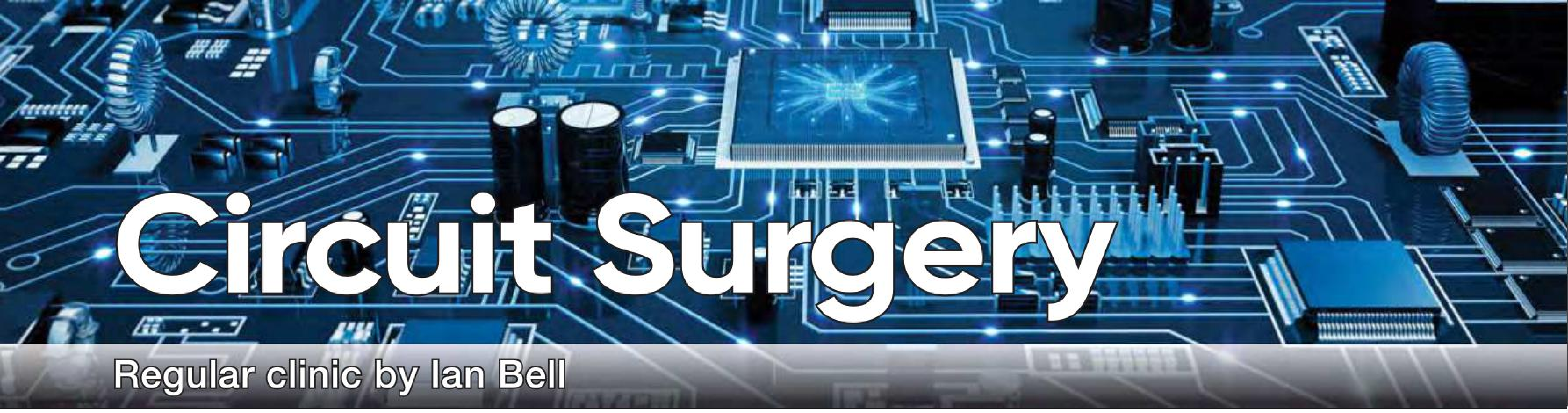


Circuit Surgery

Regular clinic by Ian Bell

Op amp offsets – Part 2

Last month, we started to discuss op amp offsets in response to a question on the EEWeb Forum from user Deion about precision op amps. After quoting the OP97 datasheet from Analog Devices, Deion asked, 'What confused me is the range of temperature? Should the resistor be balanced?'. We briefly considered the temperature range (this is stated on the device datasheet) and then looked at input offset voltage, the modelling of offsets, LTspice simulation of input offset voltage and the concept of noise gain. We will quickly recap some key points and then look at offsets due to bias currents flowing into the op amp – this is where we get to the question of balancing resistors, which Deion was asking about.

Voltage offsets recap

In simple terms, offsets are DC errors in a circuit's output due to imperfections in the circuit or components – they are amplified and processed by the circuit causing errors in the output. Offsets drift due to changes in temperature, aging and other factors that influence the circuit. Offsets are important in DC and very low frequency circuits because they cannot be blocked without blocking the wanted signal. In other cases, unwanted DC output may be damaging to a load intended to be just driven by an AC signal. The only solution is to design circuits with inherently low offsets. Op amps having low offsets as a key characteristic are often referred to as 'precision' op amps, like the OP97 mentioned by Deion.

For an op amp, ideally, with a differential input of zero, the output should also be zero, but with real op amps there will typically be a non-zero output. The input offset voltage (V_{IO}) is defined as the DC voltage which must be supplied between the inputs to force the quiescent (zero-input signal) open-loop output voltage to zero. For analysis purposes we can replace an op amp with an offset with an ideal op amp plus an offset voltage source (see Fig.1). The offset (and other imperfections, such as noise) represented in this way is called 'input referred'.

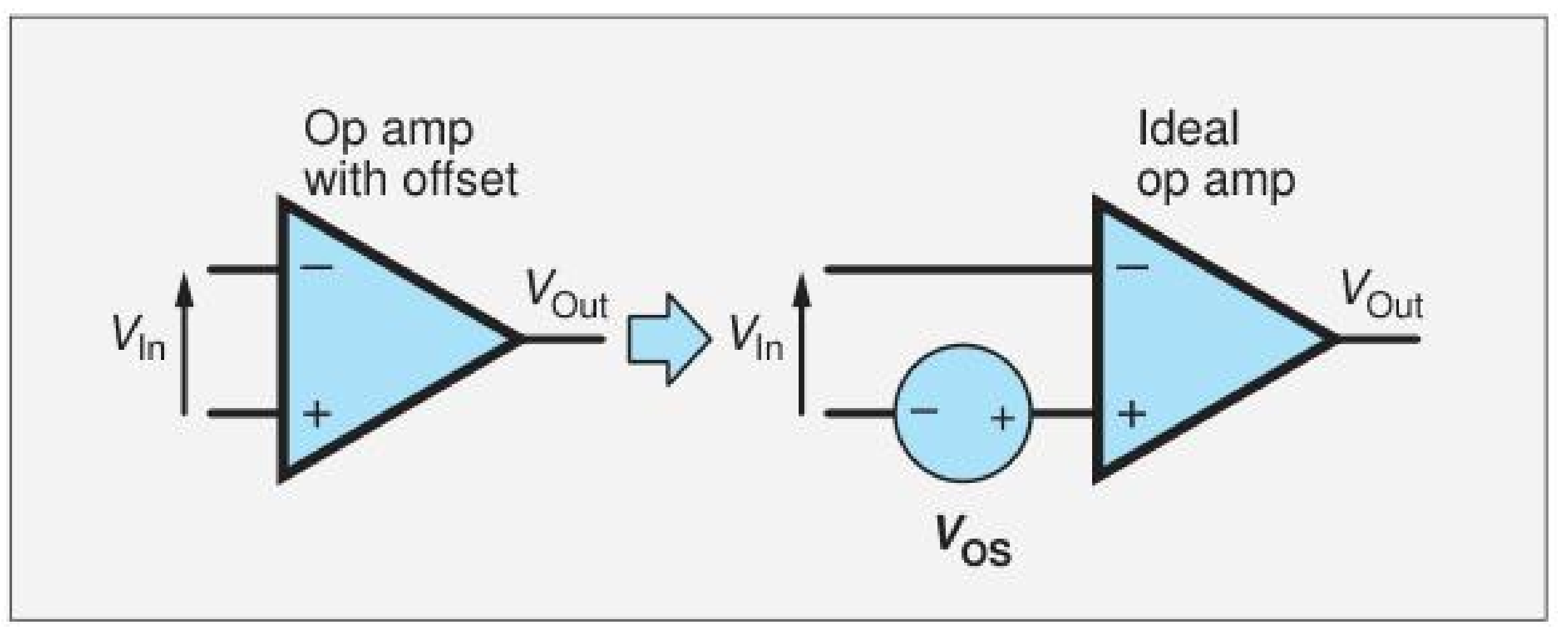


Fig.1. An op amp with offset can be modelled as an ideal op amp with an offset voltage source at its non-inverting input.

Use of input-referred voltages sources to represent offset and noise leads to the idea of 'noise gain'. The noise gain of an op amp circuit is the gain which applies to a voltage applied directly to the op amp's inputs. It is equal to the *non-inverting* gain – including circuits configured as *inverting* – as far as the signal is concerned.

Even with a low offset op amp, users may want a circuit to have the facility to manually adjust the offset to minimise (or null) it. This feature is provided by some op amps, including the OP97. Typically, if offset adjustment is available, the op amp will have two pins labelled 'Null', to which a trimmer potentiometer is connected for offset nulling – the data sheet must be consulted for the exact details of how to do this for a given device.

Bias currents

When analysing op amp circuits, it is often convenient to assume that no current flows into the op amp. This is useful because it simplifies circuit analysis and is often justified because the currents flowing into op amps in typical circuits tend to be much smaller than the currents in external components such as the gain-setting resistors. However, in some cases the input currents cannot be ignored as they can impact the performance of the circuit.

In a basic bipolar junction transistor (BJT) op amp circuit, current must flow into an op amp to bias the transistors in the input stage (to provide their base current). For FET-input devices the bias currents will usually be much smaller as FETs do not have bias current into their gates; however, there will be leakage currents. For BJT circuits it is possible to include internal circuitry to deliver the bias, which greatly reduces the external currents. This means that the amount of current will vary significantly between different types of op amp.

The input bias current (I_{IB}) is defined as the average current into the two inputs (I_{B1} and I_{B2}) with the output at zero volts (see Fig.2):

$$I_B = (I_{B1}+I_{B2})/2$$

This can vary greatly for different types of op amp, from femtoamps ($1\text{fA} = 10^{-15}\text{A}$) to tens of microamps, with tens to hundreds of nanoamps being typical for op amps with BJT input stages.

Ideally, an op amp would have perfectly symmetrical inputs, which would therefore both take the same bias current; however, in the real world, the currents are different (either input may have the larger current). Input offset current (I_{IO}) is defined as the magnitude of the difference between the currents into the two inputs with the output at zero volts:

$$I_{OS} = \mid I_{B1} - I_{B2} \mid$$

Bias currents, and offset current, will change with temperature – the temperature coefficient for these parameters will indicate the amount of change expected from a given op amp type.

In a similar way to modelling the offset voltage with a voltage source and an ideal op amp (as shown in Fig.1) bias currents can be modelled with an ideal op amp and external current sources, as shown in Fig.3. For bias designated as flowing *into* the op amp, the current sources connect from the inputs to the most negative point in the circuit (typically negative

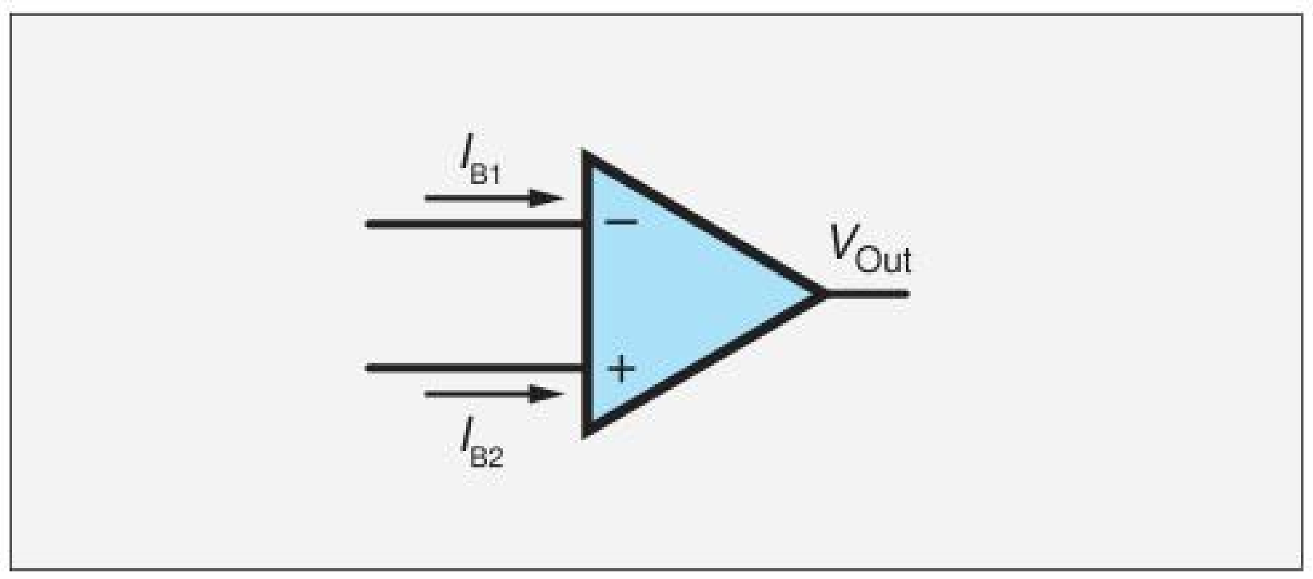


Fig.2. Input bias currents.

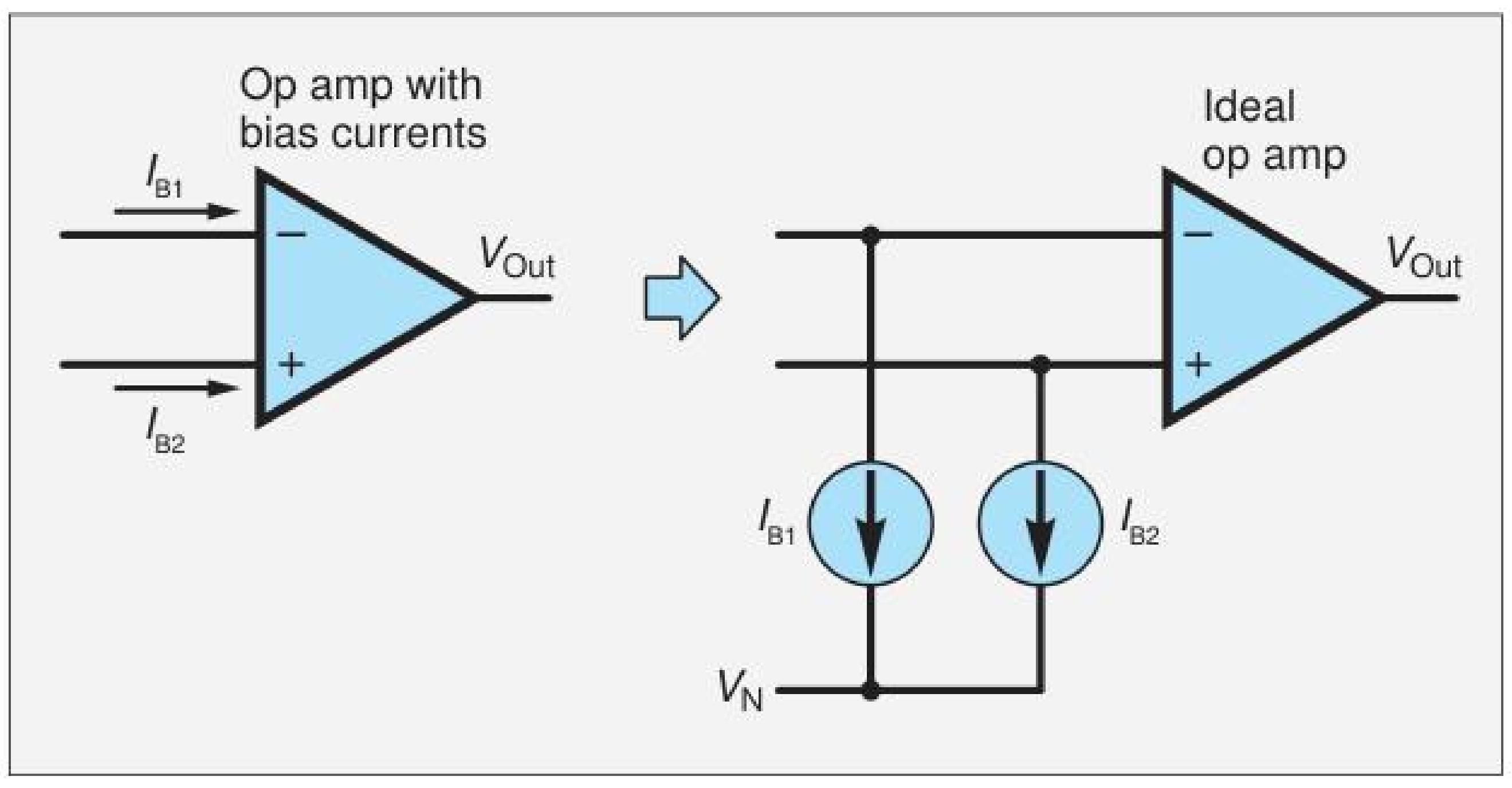


Fig.3. Modelling input bias currents.

supply or ground, V_N in Fig.3). The sources cause the bias currents to flow in the external circuit as if they were being taken by the op amp's inputs. The current sources are not connected to flow into the op amp itself. If this was done with a totally ideal op amp the current could not flow into the open circuit at the op amp's input. If the op amp's inputs are modelled with large input resistance then current forced to flow into the input would create a voltage drop which does not occur in a real circuit.

Offsets due to bias currents

Bias currents flow in the external components connected to the op amp (eg, the resistors used to set the gain) and so cause voltage drops. Differences in the bias currents for each input and/or the external impedance connected to the two inputs will cause these voltage drops to be different at each input. This difference will be amplified and appear as an offset voltage at the output.

If we assume that the input offset current for an op amp is much smaller than the input bias current, then differences in voltage drops due to differences in external resistance may cause a significant offset. Under these circumstances the offset may be reduced by balancing the resistance at the two inputs – as mentioned in Deion's question. For basic op amp amplifiers (standard inverting and non-inverting circuits) this can be achieved by adding a single resistor to one of the inputs

Resistor balancing is illustrated Fig.4. The bias current to the inverting input flows through R_1 or R_2; so, making R_3 equal to the parallel combination of R_1 and R_2 will result in the same voltage at the two inputs *due to the bias currents* (assuming the bias currents are equal).

Resistor balancing

We can analyse the resistor balancing requirement in more detail using some basic circuit theory, along with assuming the op amp is ideal apart from the bias currents. Referring to Fig.4, we note there are two sources of interest – the two bias currents – and we potentially also have the input voltage to take into consideration. We assume that the circuit is linear – the circuit is a linear amplifier, and we are not considering situations such as the output voltage being limited by the supply (this would be nonlinear behaviour).

For linear circuits we can use superposition to deal with multiple sources – we set all sources except one to zero and find the effect of that source on its own (for example, its contribution to output voltage), then repeat with the other sources. Finally (because the circuit is linear) we can add up the individual contributions. We do not have to consider all the sources if we are only interested in the effects of one in particular. In this case we do not need to include the input voltage as the offset will just be added to the amplified input at the output (again linear behaviour) and we are only interested in the offset itself here.

We start by finding the output voltage (in the circuit in Fig.4) due to I_{B1} (set $I_{B2} = 0$ and $V_{in} = 0$). The fact that $I_{B2} = 0$ means that the voltage across R_3 is zero and hence the non-inverting input is at 0V. I_{B1} flowing in the resistors R_1 and R_2 will cause a non-zero voltage at the inverting input which will be amplified. Because the gain of the op amp is very large, the voltage across R_2 (the output voltage) will be much larger than the voltage across R_1 (the op amp input voltage). This implies that almost all of I_{B1} flows in R_2. So, we assume that all of I_{B1} flows in R_2, implying the voltage across it is $I_{B1}R_2$. One end of R_2 is at V_{out} and we can assume the other end is at 0V because the voltage between an op amp's inputs during normal operation in a feedback circuit is close to zero, and, as already noted, the non-inverting input is at 0V. So, the contribution to the output from I_{B1} is:

$$V_{out} = I_{B1}R_2$$

Next, we find the output voltage due to I_{B2} (set $I_{B1} = 0$ and $V_{in} = 0$). The current I_{B2} flows through R_3 to produce a voltage of $-I_{B2}R_3$ at the op amp's non-inverting input (negative because of the direction assigned to the current in Fig.4). Since the input of the circuit is connected to ground in this part of the analysis ($V_{in} = 0$) it behaves as a non-inverting amplifier as far as the voltage across R_3 is concerned. The gain of this amplifier is found using the usual formula ($A = 1 + R_2/R_1$), thus the contribution to the output from I_{B2} is:

$$V_{out} = -I_{B2}R_3(1 + R_2/R_1)$$

To find the total output due to the bias currents we add up these contributions:

$$V_{out} = I_{B1}R_2 - I_{B2}R_3(1 + R_2/R_1)$$

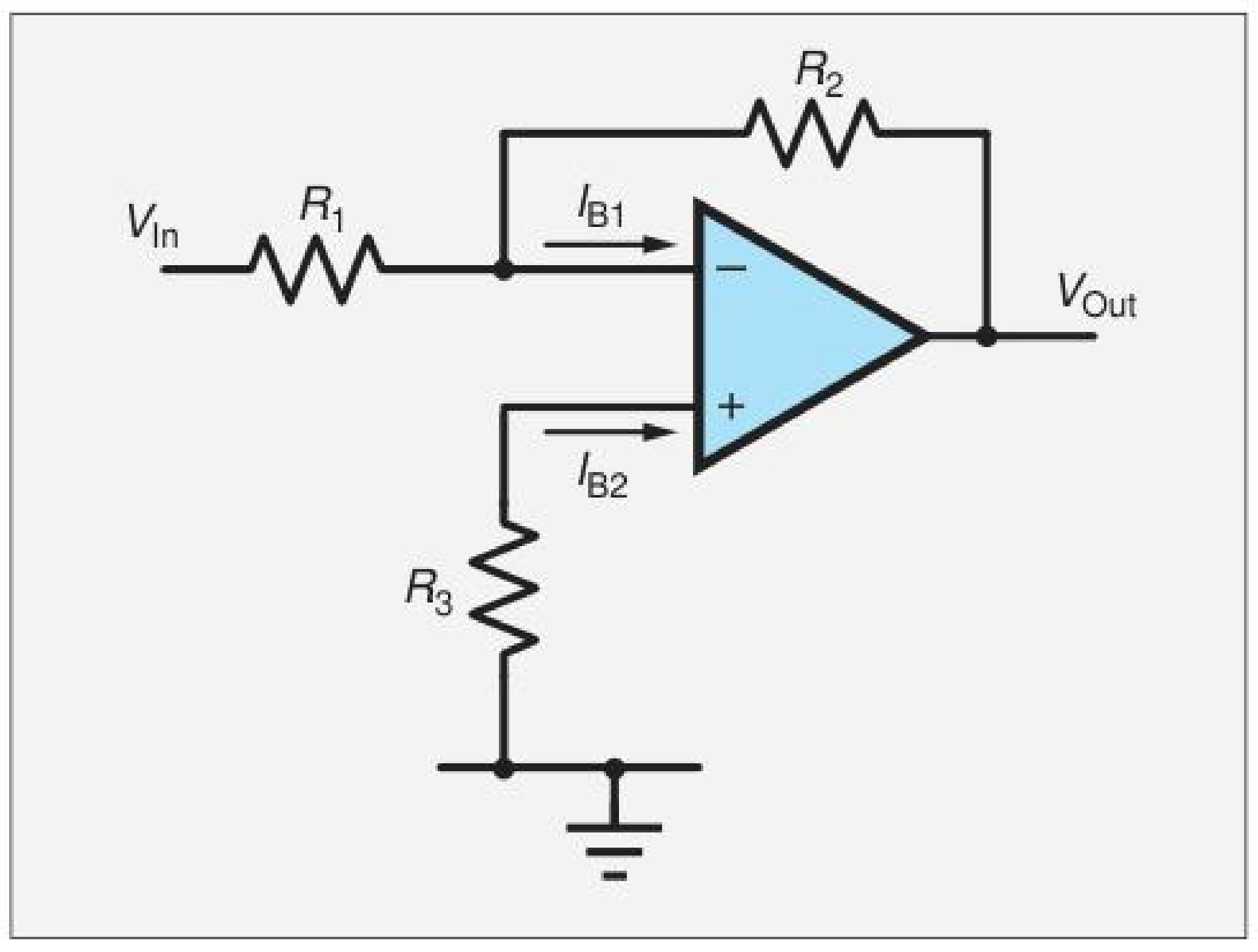


Fig.4. Minimising offset due to bias currents using resistor balancing in an inverting amplifier.

Now, assuming $I_{B1} = I_{B2} = I_B$ and given that ideally we want $V_{out} = 0$, we put these conditions into the above equation. This means that I_B can be cancelled to leave just a relationship between the resistors required to achieve $V_{out} = 0$ (zero offset), as shown below:

$$0 = I_BR_2 - I_BR_3(1 + R_2/R_1)$$
$$I_BR_2 = I_BR_3(1 + R_2/R_1)$$
$$R_2 = R_3(1 + R_2/R_1)$$
$$R_2 = R_3(R_1 + R_2)/R_1$$

To implement the resistor balancing we need to find the value of R_3. We assume that we know R_1 and R_2 from designing the amplifier. Rearranging the resistor equation to make R_3 the subject we get:

$$R_3 = R_2R_1/(R_1 + R_2) = R_1 || R_2$$

Which you may recognise as the formula for two parallel resistors, which can be written using '||' to mean 'in parallel with'. Thus, R_3 should be equal to the parallel combination of R_1 and R_2 for minimum offset. Inserting a resistor of this value between the non-inverting input and ground reduces the offset of an inverting amplifier (given the assumptions made above about the bias currents). Similarly, with a non-inverting amplifier, a resistor equal to the parallel combination of the two gain-setting resistors is inserted between the circuit input and the op amp input (R_3 in Fig.5). The balancing resistors do not change the gain of the amplifiers.

Balancing resistors work well if the magnitude of the input bias current is larger than the input offset current. The input offset current will limit the degree to which the input voltages can be balanced. However,

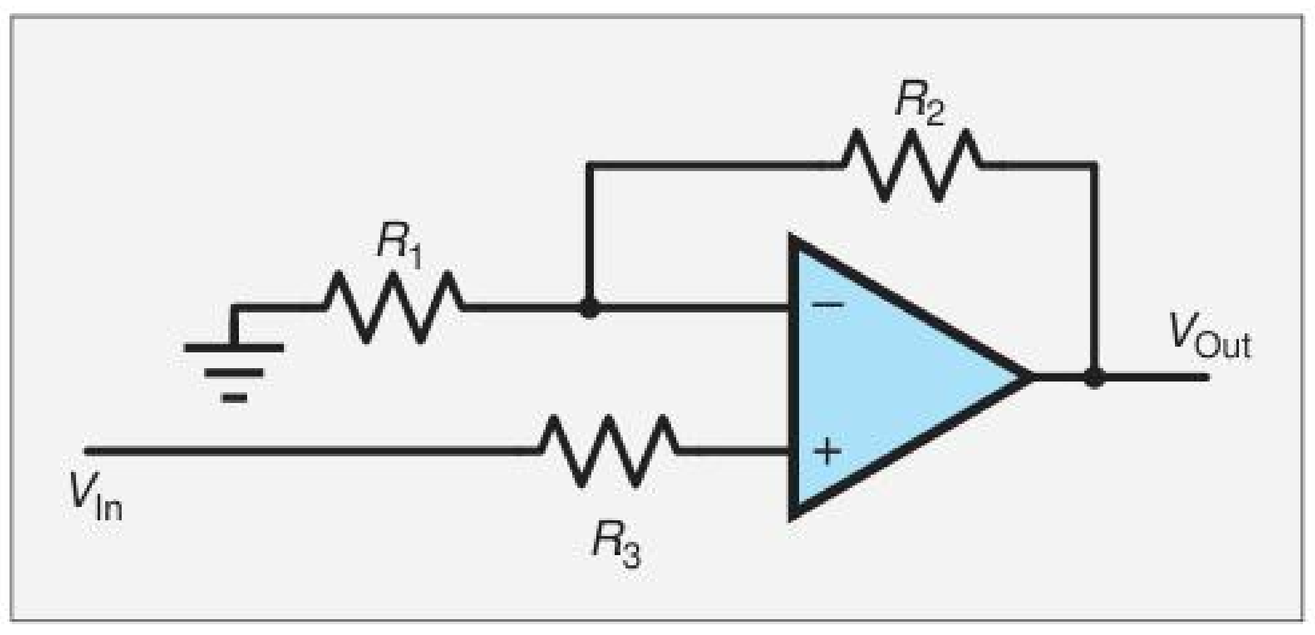


Fig.5. Resistor balancing in a non-inverting amplifier.

if the input offset current is small then the tolerance of the resistors may affect the level of balance that can be achieved (resistor variation will also result in voltage drop variation).

Update on the universal op amp

Last month, we discussed the use of the `UniversalOpamp2` component for modelling idealised op amps. We needed this to run simulations to illustrate the use of an input-referred voltage source for modelling input offset voltage (as in Fig.1). Models of real op amps would include internal modelling of their offsets, so adding the input referred voltage source would end up modelling the offset twice, and we have no control over other parameters. For investigations like this it is useful to have an op amp which is close to ideal in all aspects except the parameter(s) of interest, so you can observe the effect(s) in isolation.

The simulations in last month's article were produced using a version of LTspice which had not been updated for a few weeks, but an update was performed before working on this article. This revealed that the universal op amp component has changed recently – instead of one component called `UniversalOpamp2` there are now several versions of the component. The simulation files from last month may give an error (such as 'Unknown subcircuit called') when used with the most up-to-date version of LTspice (from late 2021 onwards).

As noted last month, the universal op amp component can model op amps with different amount of detail as set by the 'level'. Before the update there was one component and you had to edit component attributes to set the level and change any other specific parameters if required (as shown last month). The different model levels now have their own component symbols (`UniversalOpamp1`, `UniversalOpamp2` … and so on.) and there is an additional level available (level 4). To fix the error with the existing files it is necessary to delete the old symbol and insert `UniversalOpamp1` in its place and set the component attributes (`Avol` and `Rin` model parameters) as discussed last month.

Listing 1

```
--- Operating Point ---
V(in):               0                voltage
V(vp):               5                voltage
V(vn):               -5               voltage
V(n003):             -0.000909099     voltage
V(n004):             -0.000909099     voltage
V(out_balanced):     -1.04308e-007    voltage
V(n001):             -1.00025e-013    voltage
V(out_with_bias):    0.01             voltage
V(n002):             0                voltage
V(out_ideal):        0                voltage
```

Simulation example

Fig.6 is an LTspice schematic of a circuit to illustrate bias current modelling and resistor balancing. Three versions of an inverting amplifier with a gain of 10 are investigated. All three circuits use a close-to-ideal model of an op amp employing the new `UniversalOpamp1` component (level 1 op amp model) with parameters adjusted to `Avol = 100G` and `Rin = 10GΩ`, as discussed last month. The first circuit (using `U1`) has just the idealised op amp and gain-setting resistors. The second circuit (using `U2`) models input bias currents using current sources as discussed above. The third circuit (using `U3`) adds a balancing resistor (`RB3`) equal to the parallel combination of the gain setting resistors (10kΩ | | 100kΩ = 9.091kΩ).

The simulation runs an operating point analysis which provides the results shown above in Listing 1.

The output voltage for the ideal case is 0V (no offset). With the bias currents added the offset at the output is 10mV (0.01) which is 100nV × 100kΩ: the voltage drop of the bias current flowing in the feedback resistor. Adding the balancing resistor reduces the offset to about 0.1µV (–1.04308e–007) illustrating that under the correct circumstances adding a balancing resistor can significantly reduce offsets due to bias currents.

Internal input bias

Successful use of a balancing resistor depends on the input voltage differences due to the bias currents without the added resistor being larger than any other effects that might be caused with the resistor in place. This is not always the case in real circuits.

The basic scenario (for a BJT op amp) is that the bias currents are primarily due to the base currents of the op amp's input transistors, and these are well matched, so the two bias currents are almost equal (I_B much larger than I_{OS}). Fig.7 shows a very basic differential amplifier which could be the input stage of an op amp (real op amps are more sophisticated, but this illustrates the point). With no signal (V_{In1} and V_{In2} at 0V) the current from the DiffAmpBias current source (I_{BDiff}) splits equally between the matched transistors. For this current to flow in the emitters, base current must flow into the bases. The base current is $I_{BDiff}/2\beta$, where β is the transistor's current gain. This is the input bias current. Imperfect transistor matching will result in slightly different base currents, giving the offset current.

Because the direction of bias current is fixed by the transistor type (NPN or PNP) the direction of the input bias current

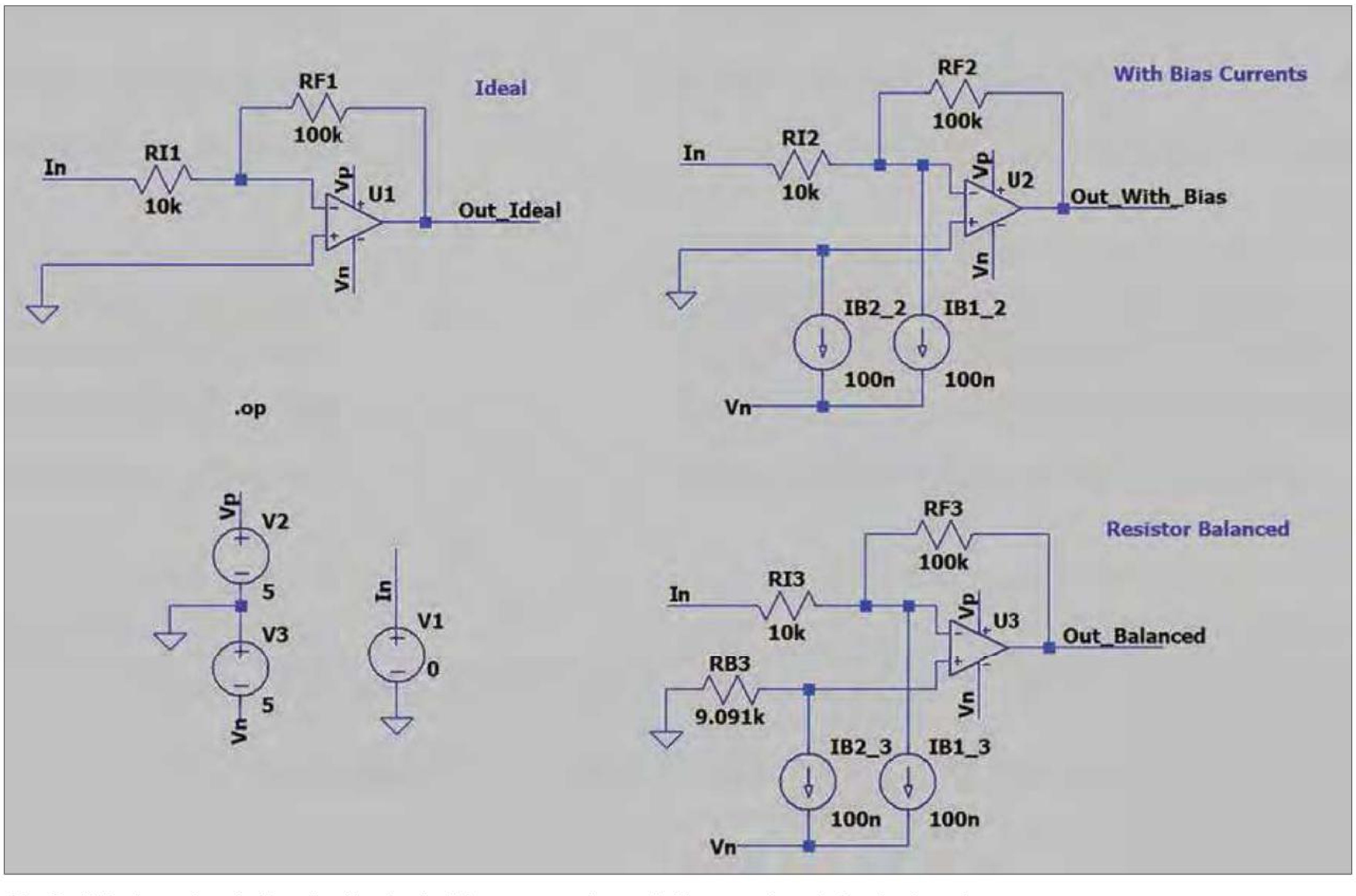


Fig.6. LTspice simulation to illustrate bias current modelling and resistor balancing.

Listing 2

```
--- Operating Point 2 ---
V(in):              0               voltage
V(vp):              5               voltage
V(vn):              -5              voltage
V(n003):            9.09099e-005    voltage
V(n004):            9.09099e-005    voltage
V(out_balanced):    0.00200001      voltage
V(n001):            -9.99025e-015   voltage
V(out_with_bias):   0.001           voltage
V(n002):            0               voltage
V(out_ideal):       0               voltage
V(out_ideal):       0               voltage
```

will also be fixed. Typically, for this situation the input offset current will be ten or more times smaller than the input bias current and resistor balancing will probably work. However, some op amps have internal circuitry to supply the bias current – the bases of both input transistors are connected to current source circuits that supply (almost) exactly the required bias current – see Fig.8. The DiffAmpBias current source provides I_{BDiff} to set up the emitter currents and the required base current (input bias current, I_{Bin}) is supplied by the InputBias1 and InputBias2 sources. The base current can be obtained by deriving half of I_{BDiff} using the same reference as DiffAmpBias, passing this through a transistor matched to Q_1 and Q_2 and using its base current as a reference for the InputBias current sources.

Balancing resistor fail

For op amps with internal biasing, the external current is the difference between the supplied internal bias and the base current the transistor actually takes (see Fig.8). The specified op amp input 'bias current' is this small current difference, not the full transistor bias, but it is still referred to as the input bias current on datasheets. We have a balance between two almost equal quantities, which are both subject to natural variation, so the average magnitude and amount of variability are of the same order and the input current to the op amp can be of either polarity. Op amps with internal input biasing tend to have similar values for input bias current and input offset current (I_B similar to I_{OS}). This means that adding a balancing resistor may make little or no improvement or may actually increase the offset at the output.

As an example of this problem, if we rerun the simulation from Fig.6 with $I_{B1\_2} = I_{B1\_3}$ = 10nA and $I_{B2\_2} = I_{B2\_3}$ = –10nA to represent the possible behaviour of an op amp with internal input bias we get the results shown in Listing 2.

In this case, adding the balancing resistor doubles the output offset from 1mV (0.001) to 2mV (0.00200001).

For FET input op amps, the 'bias' currents are leakage currents from the input protection diodes and the FETs. These currents are typically much smaller than for BJT op amps but may increase significantly for input voltages near the supplies due to the behaviour of the protection diodes.

For op amps with low input bias currents, any offsets caused by them may be significantly lower than offsets due to the input offset voltage. If this is the case then adding a balancing resistor will not make much difference to the overall offset, even if it does produce a small improvement. Another possible issue with adding a balancing resistor is that it will contribute random noise to the circuit. Larger resistors and larger circuit gains will result in more noise at the output. Noise from the balancing resistor is amplified by the circuit's noise gain.

In conclusion, balancing resistors may improve offsets, but it depends on the op amp and they are certainly not guaranteed to improve a circuit.

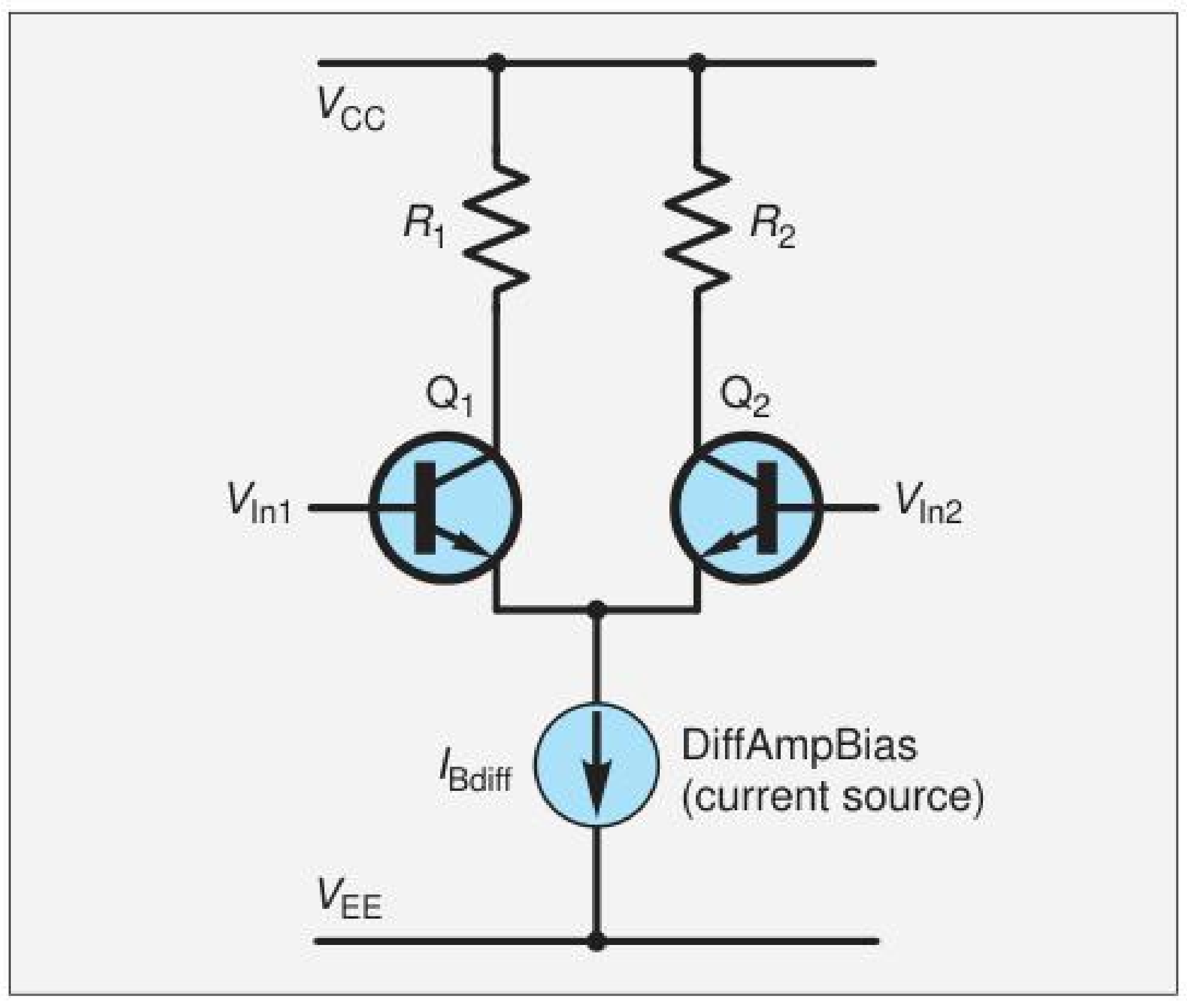


Fig.7. Basic differential amplifier.

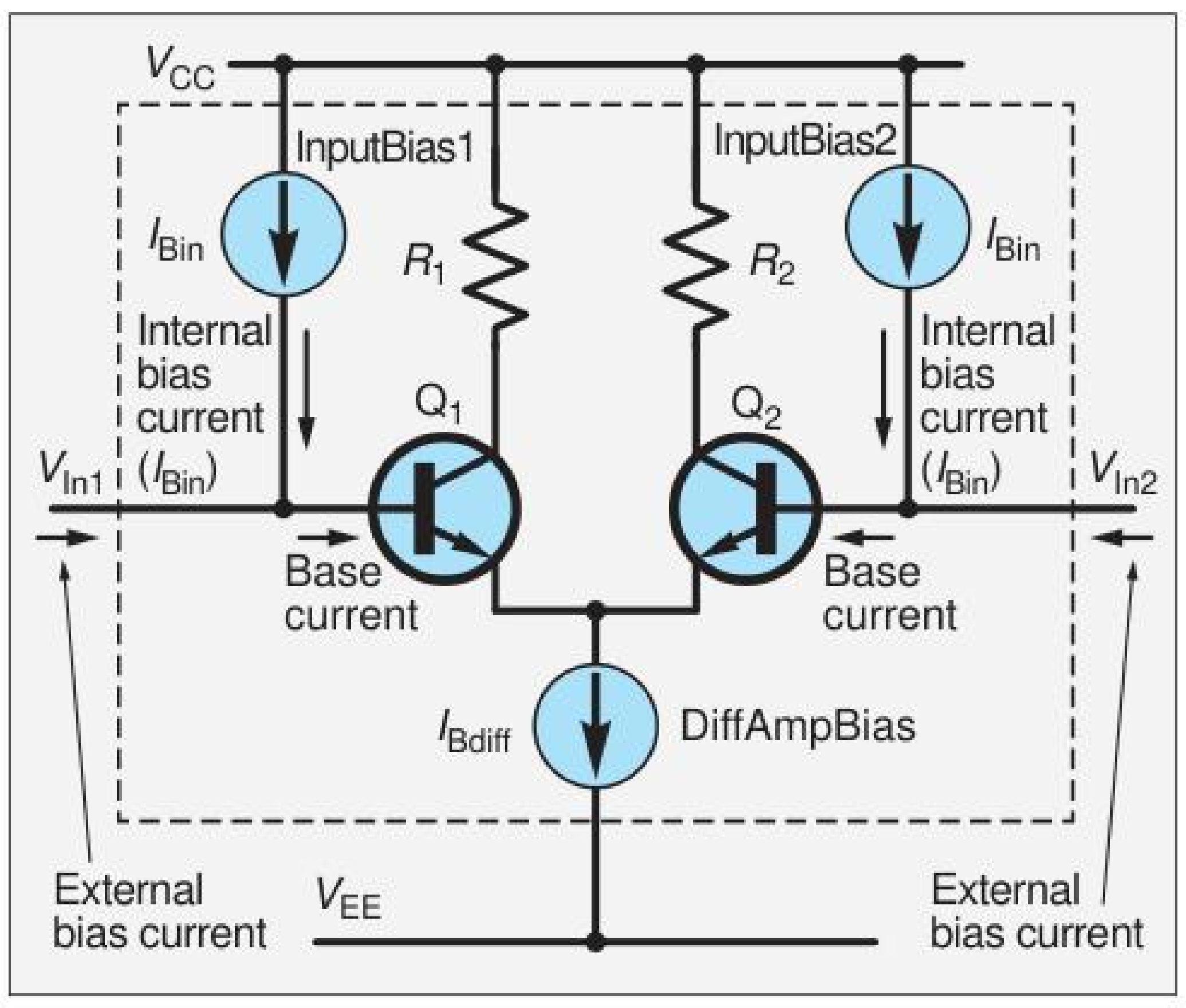
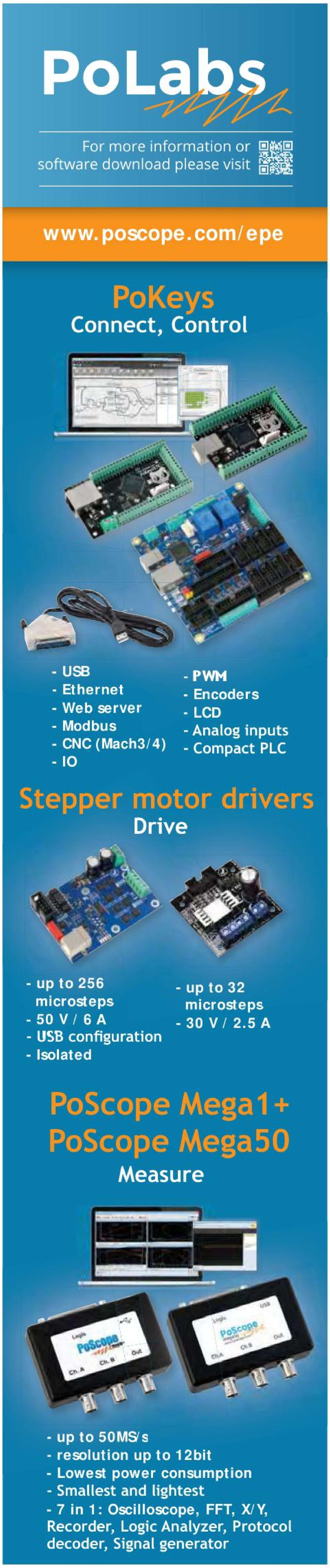


Fig.8. Differential amplifier with input bias current sources.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller

Part 34: Using the Micromite with an EEPROM iButton

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The iButton – simple, flexible and useful.

Last month, we explored how the serial data exchanged between an iButton and a Micromite can become corrupted whenever contact bounce occurs. A simple test program demonstrated how contact bounce arises when you tap an iButton onto a reader, or when it is removed from the reader. In fact, it can also occur while holding the iButton on the reader since there will always be some slight movement of the iButton, during which the contact can easily be broken – for example, caused by a dirty contact or even a shaky hand.

To address this issue, we wrote a program with an error-checking algorithm, into which we passed all the byte values read from the iButton. The resultant byte value outputted from this algorithm is compared with the CRC byte value that is also read from the iButton. If the values match, then we regard the data as valid (and not corrupted by contact bounce) otherwise we disregard the data.

Micromite code

The code in this article is available for download from the *PE* website.

So far, we have only read an iButton's unique 64-bit (8-byte) ID value which is stamped onto the iButton's case; however, if we need to send or receive more than 8-bytes of serial data (such as when communicating with an EEPROM iButton) then the likelihood of data corruption becomes greater, and so the use of the CRC algorithm becomes more critical.

To put this into practice, this month we will learn how to communicate 100% error-free with an EEPROM iButton. The iButton that we are going to use is the DS1971, so first we will look at its memory layout and the features available in the DS1971. Then we will explore the 1-wire commands that are available to communicate with it. Once these are understood, we can then write some simple code to send data to, and read data from, the EEPROM iButton. Finally, we will apply the CRC algorithm to ensure that everything works 100% error-free. This is all in preparation for the EEPROM iButton to be used as an electronic key in our upcoming *Electronic Door Lock* mini-project.

Let's begin by looking at the features of the DS1971.

DS1971 memory blocks

The DS1971 can be viewed as a DS1990 ID iButton (the one used in our previous articles) but with the addition of 32 bytes of EEPROM data storage. In fact, it also has 8 bytes of one-time-programmable (OTP) memory and a status register.

Looking at the datasheet for the DS1971, it refers to the following four 'memory blocks':

1. 64-bit lasered ROM
2. 256-bit EEPROM (with scratchpad)
3. 64-bit OTP Application Register (with scratchpad)
4. 8-bit Status register

The ROM memory block contains the iButton's unique ID number that is factory-programmed by the manufacturer. We've already met this memory block because it is what we used in the previous two articles. This memory block is read only.

The EEPROM memory block is what will be discussed in detail shortly. One thing to highlight here is that there is no direct contact with the EEPROM memory; instead, communication is via a 'scratchpad'. The scratchpad can be viewed as a safety buffer – more on this shortly.

The Application Register memory block is typically used by the end-user to program their own 8-byte serial number (or product number) into the iButton. Note that like the EEPROM memory block, this also has its own scratchpad; and once the Application Register has been programmed, it cannot be altered.

The Status register is a single byte that only uses the two least-significant bits to signify whether the Application Register has been programmed, or not. It will have a binary value of 11111111 if the Application Register has not yet been programmed, and a value of 11111100 once it has been programmed and locked. This (single-byte) memory block is read only.

Note that we are not going to be using either the Application Register, or the Status register in our mini-project, these are just mentioned here for completeness.

Please refer to Fig.1 for a summary of these four memory blocks. You will also see reference to all the available 1-wire commands that are associated with each memory block – something we will discuss next.

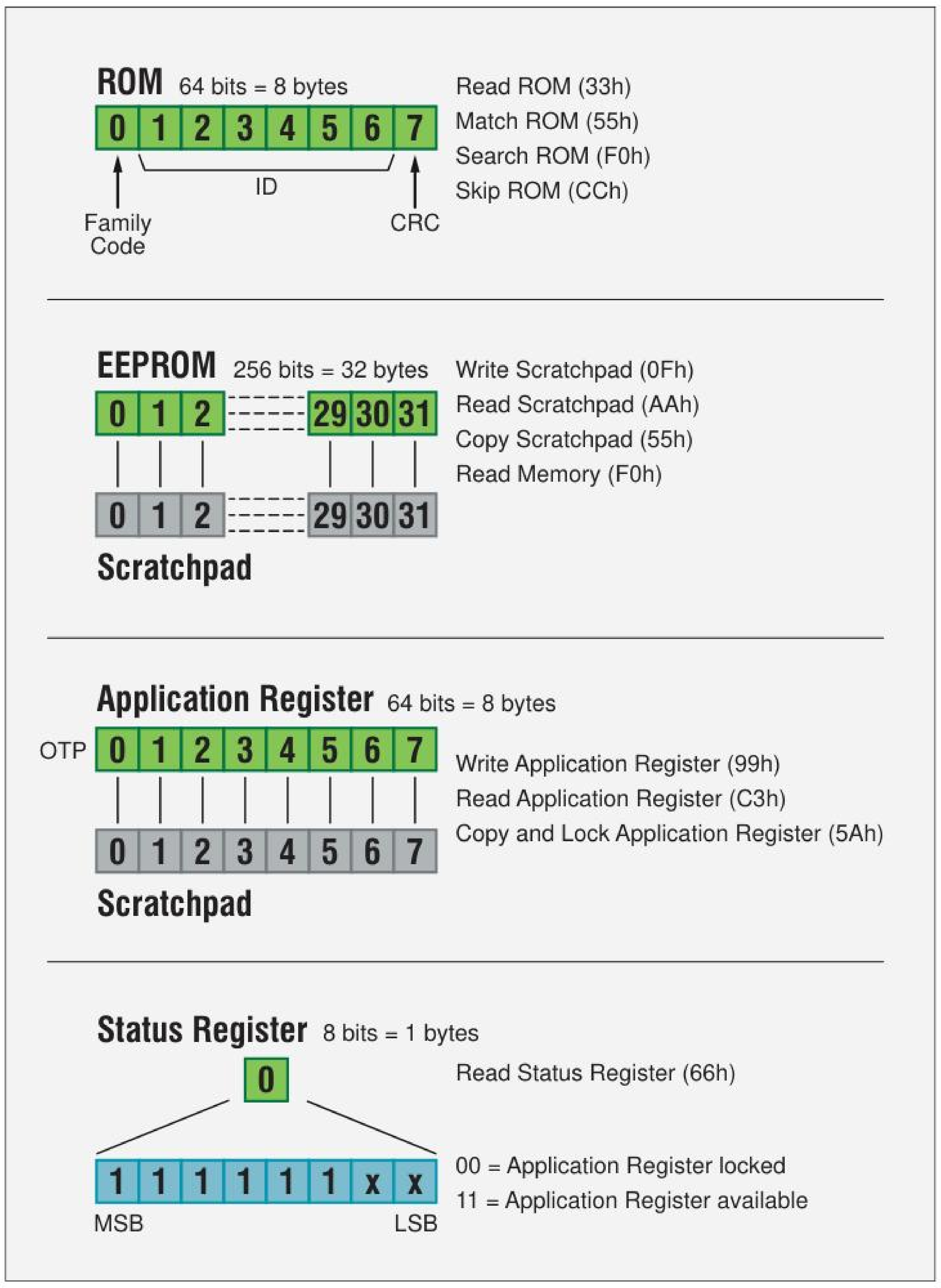


Fig.1. The DS1971 comprises four memory blocks: an 8-byte ROM, a 32-byte EEPROM, an 8-byte Application Register, and a 1-byte Status Register. Shown here are the available 1-wire commands associated with each memory block (see text for explanatory details).

1-wire commands

Each 1-wire command available for use with the DS1971 has its own command number – these are also shown in Fig.1. The relevant command number is used with the MMBASIC command `ONEWIRE WRITE` to perform the relevant action. We will now briefly describe each command in more detail, which will help us understand how the code works in the examples that we will work through later.

ROM commands

Read ROM (33h)

This command allows the 1-wire bus master (ie, the Micromite) to read the 8-byte ID number. As we have already seen, this comprises a Family Code byte, followed by a 6-byte unique ID number, and finally the CRC byte. This command can only be used when there is just a single iButton on the 1-wire bus (as there will be in our scenario when using an iButton reader). If more than one iButton is present on the 1-wire bus, then data-collisions will arise once they all start responding at the same time to the Read ROM command – something the CRC algorithm will pick up (if implemented).

Match ROM (55h)

This command allows the bus master to address a particular iButton. It does this by specifying the unique ROM ID of the iButton it wishes to communicate with. The Match ROM command solves the issue of multiple iButtons present on the 1-wire bus. Only the iButton with a matching ID number (if present) will respond to this command, all other iButtons simply won't respond. Instead, they just wait for a reset signal from the bus master on the 1-wire bus.

Search ROM (F0h)

This command is used when the bus master doesn't know how many iButtons are present on the 1-wire bus, or when their ID numbers are not known (and hence can't be addressed by an ID number). It is quite complex in its use, and since we are not going to be using this command, we will not go into any further details this month.

Skip ROM (CCh)

This command is used to save time when addressing an iButton. It can only be used when there is just a single iButton on the 1-wire bus. After a reset signal has been sent by the bus master on the 1-wire bus, any communication must begin with a ROM command. By using the Skip ROM command, the bus master may immediately start to address other memory functionality such as reading or writing to the EEPROM memory. Note that we will be using this command in the majority of the examples coming up later in this article.

EEPROM commands

Write Scratchpad (0Fh)

This command is used to write data bytes into the EEPROM's scratchpad. Note that it does not write data into the EEPROM itself. After issuing this command, the bus master must issue a 1-byte starting address (a value between 0 and 31), which is then followed by the data bytes that are to be written to the scratchpad. The DS1971 automatically increments the address after every byte it receives, and when the address reaches a value of 31, it simply wraps around to 0. The writing continues until the bus master issues a reset signal.

Read Scratchpad (AAh)

This command is used to verify the data previously written to the scratchpad before it is copied into the EEPROM memory (with the Copy Scratchpad command detailed below). After issuing the Read Scratchpad command, the bus master must issue a 1-byte starting address (a value between 0 and 31) from where the data will begin to be read. Again, the DS1971 automatically increments the address after every byte read, and when the address reaches a value of 31, it wraps around to 0. The reading continues until the bus master issues a reset signal.

Copy Scratchpad (55h)

This command instructs the DS1971 to copy the contents of the Scratchpad into the EEPROM. Ideally, it should only be used after the Scratchpad's contents have been verified (ie, after the use of the preceding Read Scratchpad command). One point to stress here is that all 32 bytes from the scratchpad are copied into the EEPROM. After issuing the Copy Scratchpad command, the bus master must issue a validation key, which simply means sending a single byte with a value of A5h. Furthermore, the bus master must then keep the 1-wire line at a high logic level for a minimum specified period. In practice, this simply means pausing for 10ms between sending both the command and validation key, and before the bus master sends the reset signal. Note that if the validation key is not sent (or is sent with any other value), or the 1-wire bus is not held high for the required time, then the scratchpad contents will not be copied into the EEPROM.

Read Memory (F0h)
This command is useful when you need to change part of the EEPROM's content. On receipt of this command, the iButton will first copy the entire contents of the EEPROM memory into the scratchpad. The bus master may also optionally send a 1-byte starting address value (between 0 and 31) from which the data can then be read from the scratchpad. The usual automatic incrementing of the address will occur (with wrap around from 31 to 0) until a reset signal is sent by the bus master.

This command is typically used without sending a starting address – or put another way, it is used to simply copy the EEPROM contents into the scratchpad. This saves the bus master needing to keep a local copy of the EEPROM contents should the bus master only need to change a few bytes of the EEPROM memory. Remember that the Copy Scratchpad command copies all 32-bytes from the Scratchpad into EEPROM, so by using the Read Memory command first, the bus master can then simply use the Write Scratchpad command to update just the bytes in the Scratchpad that need to be updated (by passing the relevant starting address in the Write Scratchpad). Then, to update the EEPROM, the Copy Scratchpad command is sent.

Note that we will not be using the Read Memory command to update just some of the EEPROM memory. Instead, we will use the Write Scratchpad to send a full set of 32 data bytes to the scratchpad, then use the Read Scratchpad command to ensure that the 32 bytes just written (to the scratchpad) are correct. If they are, then we will finally use the Copy Scratchpad command to load the 32 data bytes into EEPROM. In essence, we overwrite the 32 bytes each time, rather than partially modify the contents of the EEPROM.

Application Register commands

We will not be using any of the following Application Register commands since we will not be using the Application Register in our mini-project. However, we will briefly explain their functionality.

Write Application Register (99h)
This command is used to write data bytes to the Application Register. It behaves in a similar way as the EEPROM Write Scratchpad command but operates with the Application Register scratchpad as opposed to the EEPROM scratchpad. Note that the Application Register is only 8-bytes long and hence the supplied starting address value must be between 0 and 7, with wrap around happening from 7 to 0. If the OTP Application Register has previously been written to (and hence locked), then any data written to the Application Register scratchpad will be lost. Writing data to the Application Register is terminated as soon as the bus master sends a reset signal.

Read Application Register (C3h)
This command will read data from the Application Register scratchpad (if it is not locked), or directly from the Application Register (if it is locked). Refer to the Read Status Register command below for how to check the status of the Application Register. A starting address must also be supplied as part of this command. The address must be a value between 0 and 7, with wrap around happening from 7 to 0. Reading data from the Application Register is terminated as soon as the bus master sends a reset signal.

Copy and Lock Application Register (5Ah)
This command should only be used after the above two commands have been used. So, once the bus master has written and verified the contents of the Application Register's scratchpad, this Copy and Lock Application Register command is sent, and must also include a validation key data byte (with a value of A5h). In addition, the 1-wire bus must be held high for a minimum time before a reset signal is sent. Once these conditions have been met, the entire 8-byte content of the Application-Register's scratchpad will be written into the Application Register's OTP memory. This command needs to be used very carefully because it will immediately write protect the 8 bytes of the OTP Application Register memory, and at the same time it will update the Status Register (see below). Note that the bus master may cancel this command by sending a reset signal instead of sending the validation key (A5h). Further write access to the Application Register will be denied and hence this command can only be executed once.

Status Register command

Read Status Register (66h)
The Status register is a read-only, single-byte memory location that the bus master can interrogate to see if the OTP Application Register has been previously programmed, and hence locked. After issuing the Read Status Register command, the bus master needs to send a validation key data byte with a value of 00h, after which the DS1971 will send the value stored in the Status Register. As mentioned previously, the two least-significant bits of the 8-bit Status Register are 0 if the Application Register has previously been programmed and locked (all other bits will always bet set to 1). The bus master sends a reset signal to terminate the command.

From theory to code

Now that we have a theoretical understanding of the steps involved in writing data to the EEPROM, and subsequently reading the data back from the EEPROM, we should now apply this theory to create some functioning MMBASIC code. We will therefore work through two simplified examples; the first being to write some data into the EEPROM (just seven bytes for now), with the second example showing you how to read these seven bytes back from the EEPROM.

To make these two examples easier to follow, we will not incorporate the CRC algorithm at this stage, nor will we check the type of iButton tapped onto the reader – we will just assume that it is a DS1971. All error checking will be added in a more complex third example, which is available to download from the March 2022 page of the *PE* website (file **EEPROMiButtonDemo.txt**).

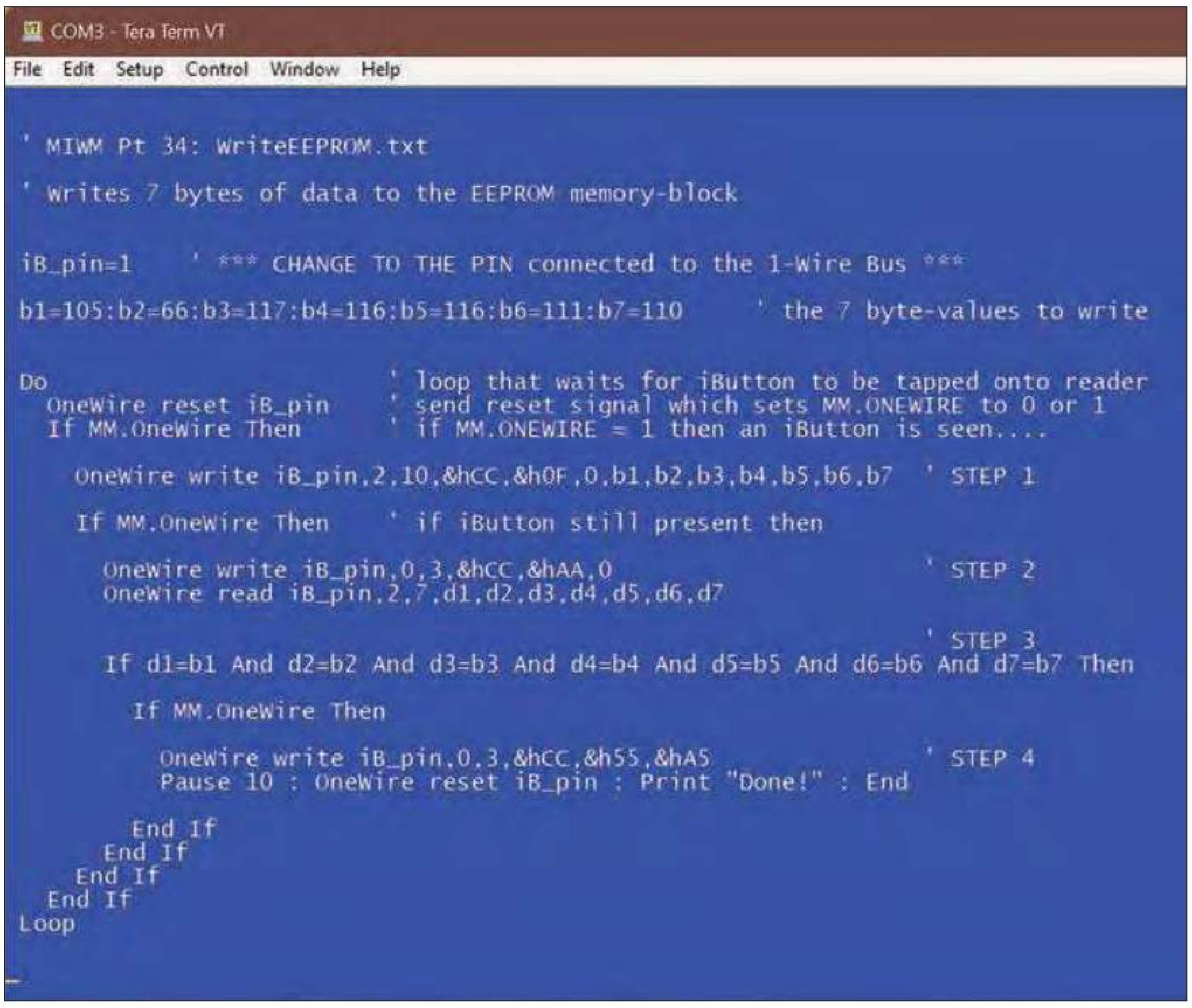
Example 1: Writing data to EEPROM

The full code for this demonstration is also available from the March 2022 page of the *PE* website. The file you require is **WriteEEPROM.txt**

The four theoretical steps involved in successfully writing data to the EEPROM are:

1. Write the seven bytes to the scratchpad in the relevant address (with the Write Scratchpad command)
2. Read the seven bytes back from the scratchpad from the relevant address (with the Read Scratchpad command)
3. Compare what we sent in Step 1 with what we read back in Step 2
4. If the Step 3 data matches correctly, then send the Copy Scratchpad command

Let's now examine how these four steps translate into MMBasic code. Note that the full program download has a few additional lines of code that essentially keep checking that the iButton is still present on the 1-wire bus; however, the following explanation should help in understanding how the **WriteEEPROM.txt** program works. Do also refer to Appendix C in the *Micromite User Manual* that gives the detail of the `ONEWIRE WRITE`, `ONEWIRE READ` and `ONEWIRE RESET` commands, as well as referring to the 1-wire command numbers mentioned earlier in this article.



```
' MIWM Pt 34: WriteEEPROM.txt

' Writes 7 bytes of data to the EEPROM memory-block

iB_pin=1     ' *** CHANGE TO THE PIN connected to the 1-Wire Bus ***

b1=105:b2=66:b3=117:b4=116:b5=116:b6=111:b7=110      ' the 7 byte-values to write

Do                         ' loop that waits for iButton to be tapped onto reader
  OneWire reset iB_pin     ' send reset signal which sets MM.ONEWIRE to 0 or 1
  If MM.OneWire Then       ' if MM.ONEWIRE = 1 then an iButton is seen....

    OneWire write iB_pin,2,10,&hCC,&h0F,0,b1,b2,b3,b4,b5,b6,b7  ' STEP 1

    If MM.OneWire Then     ' if iButton still present then

      OneWire write iB_pin,0,3,&hCC,&hAA,0                      ' STEP 2
      OneWire read iB_pin,2,7,d1,d2,d3,d4,d5,d6,d7

                                                                ' STEP 3
      If d1=b1 And d2=b2 And d3=b3 And d4=b4 And d5=b5 And d6=b6 And d7=b7 Then

        If MM.OneWire Then

          OneWire write iB_pin,0,3,&hCC,&h55,&hA5               ' STEP 4
          Pause 10 : OneWire reset iB_pin : Print "Done!" : End

        End If
      End If
    End If
  End If
Loop
```

Fig.2. The **WriteEEPROM.txt** program has four main steps (labeled above) to complete the process of writing data to the EEPROM memory block.

1.
```
ONEWIRE WRITE iB_pin,2,10,&hCC,&h0F,0,b1,b2,
b3,b4,b5,b6,b7
```

This line of code sends data on the 1-wire bus which is connected to the pin defined by variable `iB_Pin`

The `2` parameter is the flag parameter, as defined in the *User Manual*. When set to a value of `2`, it means that a reset signal is sent after all the other bytes have been sent. The `10` parameter then defines how many data bytes will be sent on the 1-wire bus, with the first byte being the hex value `CC`. From the above command numbers, you will see that this is the Skip ROM command. The next byte is the hex value `0F` which is the Write Scratchpad command. This requires the starting address to be sent next (ie a value between `0` and `31`). Here the starting address is defined by the next data byte: `0` (which effectively means the first location in the scratchpad). The seven bytes are then sent from the variables `b1` to `b7`. This completes the process of writing the seven bytes into the EEPROM's scratchpad.

2.
```
ONEWIRE WRITE iB_pin,0,3,&hCC,&hAA,0
ONEWIRE READ iB_pin,2,7,d1,d2,d3,d4,d5,d6,d7
```

The first line of code above sends three bytes of data on the 1-wire bus without sending a reset signal afterwards (since the flag parameter is set to `0`). After the Skip ROM command is sent (`CC`), the Read Scratchpad command is sent (`AA`) and is defined to start reading from address location `0`.

The second line then reads seven bytes from the 1-wire bus into variables `d1` to `d7`, after which a reset signal is sent (as defined by the flag parameter value of `2`). This reset signal is required to terminate the reading process.

3.
```
If d1=b1 AND d2=b2 AND d3=b3 AND d4=b4 AND
d5=b5 and d6=b6 AND d7=b7 THEN
```

This line of code should be relatively easy to understand. Essentially, it is an `IF` statement that requires all seven data bytes (`d1` to `d7`) that are read from the scratchpad in Step 2 to be the same as all seven data bytes (`b1` to `b7`) that were sent in Step 1. If they match, then the block of code inside the `IF`/`THEN`/`ENDIF` block will be executed (which is Step 4). In other words, a match will copy the Scratchpad into the EEPROM.

4.
```
ONEWIRE WRITE iB_pin,0,3,
&hCC,&h55,&hA5
PAUSE 10 : ONEWIRE RESET iB_pin
```

The first line of code above sends the Copy Scratchpad command (`55`) along with the required validation key (`A5`) without sending a reset signal (flag parameter is set to `0`). The second line pauses for 10ms, which leaves the 1-wire bus set to the required logic-high state. Then a reset signal is sent which is a requirement to complete the Copy Scratchpad command.

If you look through the code within the **WriteEEPROM.txt** program (shown in FIg.2), you should now be better placed to be able to follow how it works. Use is made of several `IF MM.ONEWIRE THEN` statements which simply ensure the iButton is still present on the 1-wire bus. Now that the seven byte values (`b1` to `b7`) have been written into EEPROM, we can look at how to read them back from EEPROM.

Example 2: Reading data from EEPROM

The process of reading data from the EEPROM is much easier than writing data to EEPROM, as we will now see. There is just one theoretical step involved, and this is the Read Memory command (command number &hF0). Remember that we are not using the CRC algorithm in this example, and hence the program listing is relatively short as shown below (with the two main lines of code being highlighted in bold):

```
DO
  ONEWIRE RESET iB_Pin
  IF MM.ONEWIRE THEN
       ONEWIRE WRITE iB_pin,0,3,&hCC,&hF0,0
       ONEWIRE READ iB_pin,2,7,d1,d2,d3,
       d4,d5,d6,d7
       PRINT CHR$(d1);CHR$(d2);CHR$(d3);CHR$(d4);
       CHR$(d5);CHR$(d6);CHR$(d7)
  END IF
LOOP
```

Type in the above listing. You can see that the program comprises a `DO`/`LOOP` that waits until an iButton is detected by checking for the system variable `MM.ONEWIRE` to be set to a value of `1`, (as explained in Part 32, *PE*, January 2022). Once an iButton is detected, the first highlighted line of code is executed. This line simply sends three bytes of data on the 1-wire bus (which is connected to the physical pin number as pointed to by the `iB-pin` variable). Note that the flag parameter is set to `0`, and hence no reset signal is sent after the three data bytes are sent. The first data byte sent (`CC`) represents the Skip ROM command, and then the Read Memory command (`F0`) is sent with the starting address defined as location `0` (the same starting address location that we used in the WriteEEPROM program). Remember that the Read Memory command copies all 32 EEPROM bytes into the scratchpad, irrespective of the starting address.

The second highlighted line then reads seven data bytes from the scratchpad (starting at address location `0`, as defined above) into the seven variables `d1` to `d7`. Finally, a reset signal is sent (because the flag parameter is set to a value of `2`), this being a requirement to terminate the Read Memory command. The `PRINT` statement then converts the seven data byte values into characters, and displays them on the Terminal screen while the iButton is held on the reader. If everything has gone to plan, you should see a seven-letter word displayed that is relevant to the topic we are working on! The `DO`/`LOOP` in the program above ensures the whole process is continually repeated. (Note that you will likely see the effects of contact bounce in the characters displayed – something we will address next.)

EEPROMiButtonDemo.txt

The two examples just worked through provide working code that allow communication with the DS1971 EEPROM iButton. However, no error checking was used, so in their current state, neither program is ready to be integrated into the final code for the upcoming *Electronic Door Lock* mini-project. To show how to make everything work 100% reliably, another example program has been written. This not only includes the CRC algorithm, but it also has a few other nice features incorporated.

Rather than go into any more detail here, we recommend that you download the file **EEPROMiButtonDemo.txt**, load it into a Micromite, and `RUN` the program. Everything should be self-explanatory regarding use, and the comments included in the code (along with the topics covered in this month's article) should help you understand how it works.

One important detail to point out here is to ensure that the line of code: `iB_pin=1` is changed to the pin number that you have connected to your 1-wire bus (ie, the pin number that connects to the iButton reader).

Next time

Now that we've finished exploring how to use iButtons with the Micromite, next month we can begin our *Electronic Door Lock* mini-project. Until then, stay safe, and have FUN!

Questions? Please email Phil at:
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Next month, we'll put our newly acquired iButton knowledge to good use with an *Electonic Door Lock* mini-project.

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Marconi 2022E	Synthesised AM/FM Signal Generator 10kHz – 1.01GHz	£325	Solartron SI 1255	HF Frequency Response Analyser	POA
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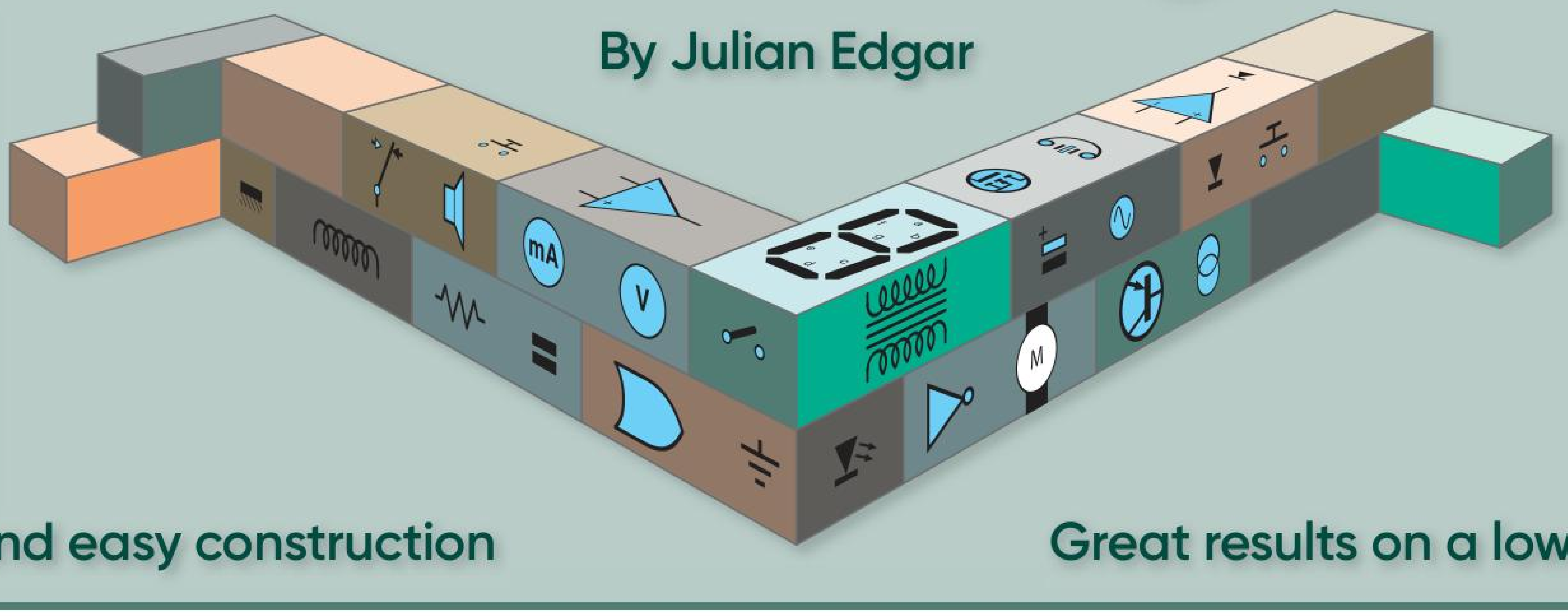
HP53131A	Universal Counter 3GHz Boxed unused	£600
HP53131A	Universal Counter 225MHz	£350
Audio Precision	SYS2712 Audio Analyser – in original box	POA
Datron 4708	Autocal Multifunction Standard	POA
Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
Keithley 228	Voltage/Current Source	POA
Time 9818	DC Current & Voltage Calibrator	POA

Marconi 2955B Radio
Communications Test Set – £800

Electronic Building Blocks

By Julian Edgar



Quick and easy construction

Great results on a low budget

Your new laptop speakers

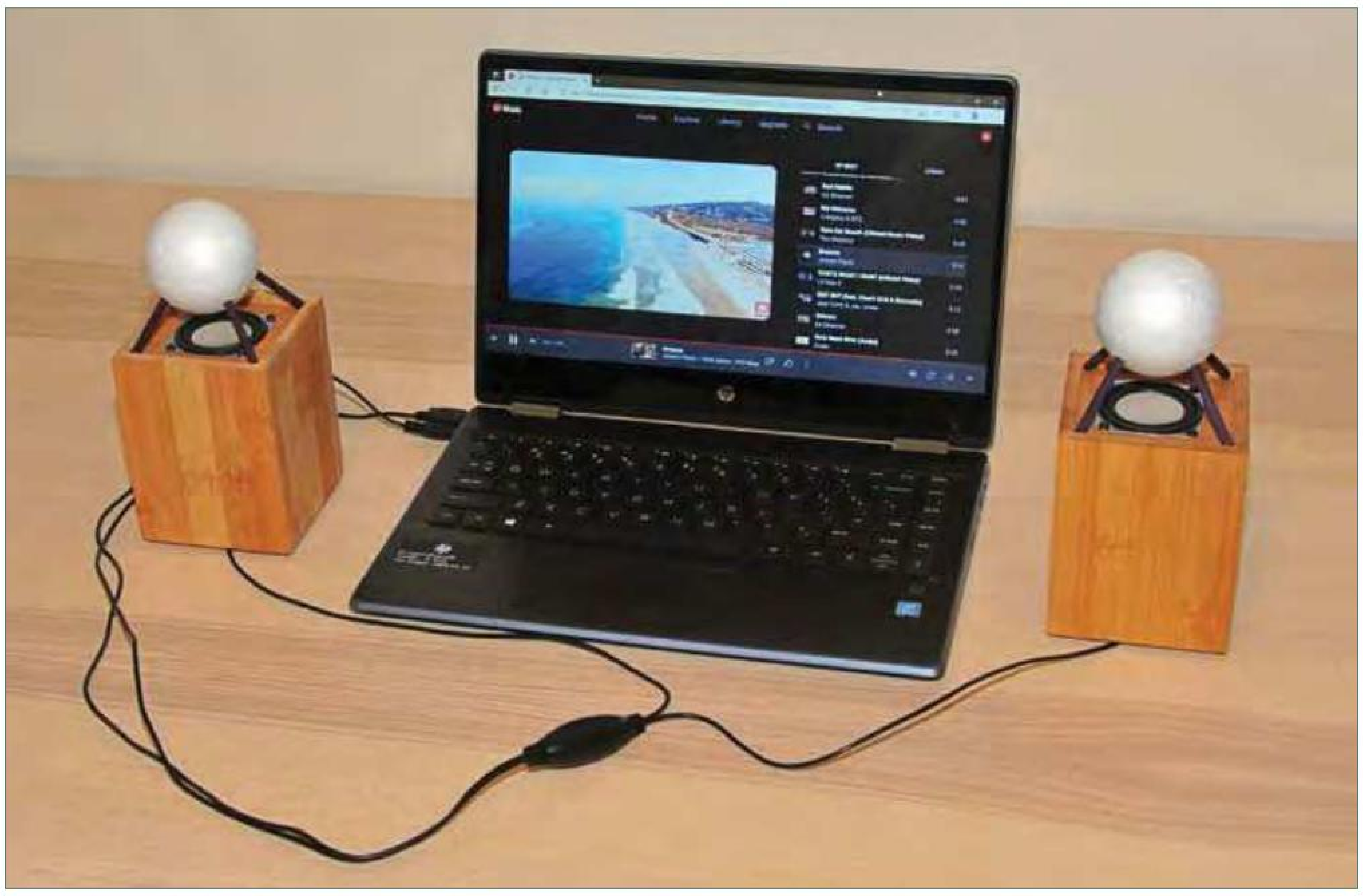
Make these fun-looking speakers for nearly no cost – and learn about speaker building at the same time. This is an ideal practical audio project for an electronics beginner or for someone with no experience of building speakers.

These DIY amplified speakers sound incredibly good for their price. Based on a Banggood kit, most of the bits will cost you just £5 to £8, depending on whether they're on special (search online for: 'EQKIT Mini Speaker DIY Kit USB Power Amplifier Wire Control Small Speaker DIY Speaker Parts' kit). And that price includes delivery! You get a tiny but effective audio amplifier (complete with volume control), a 5V USB power cable, 3.5mm stereo plug and two 50mm speaker drivers. Add some parts from the local craft shop and you have a fully fledged sound system that can be plugged into your laptop or phone.

The kit

The Banggood kit is great value for money – especially given the quality of the result. (Note that there is quite a range of 'kits' available online, so do ensure that yours matches the one shown on the next page.)

Initially, it looks like the electronics comprises just a few cables with an in-line volume control. But that 'volume control' is also an audio amplifier that uses the LTK 5206 chip. Connecting to the amplifier is a USB cable (providing power) and the jack to plug into the audio source. Coming out the other side of the amplifier are two leads with bared ends – the speaker cables.



The finished system – the amplifier and volume control are contained in the small black ellipsodal object in front of the laptop.

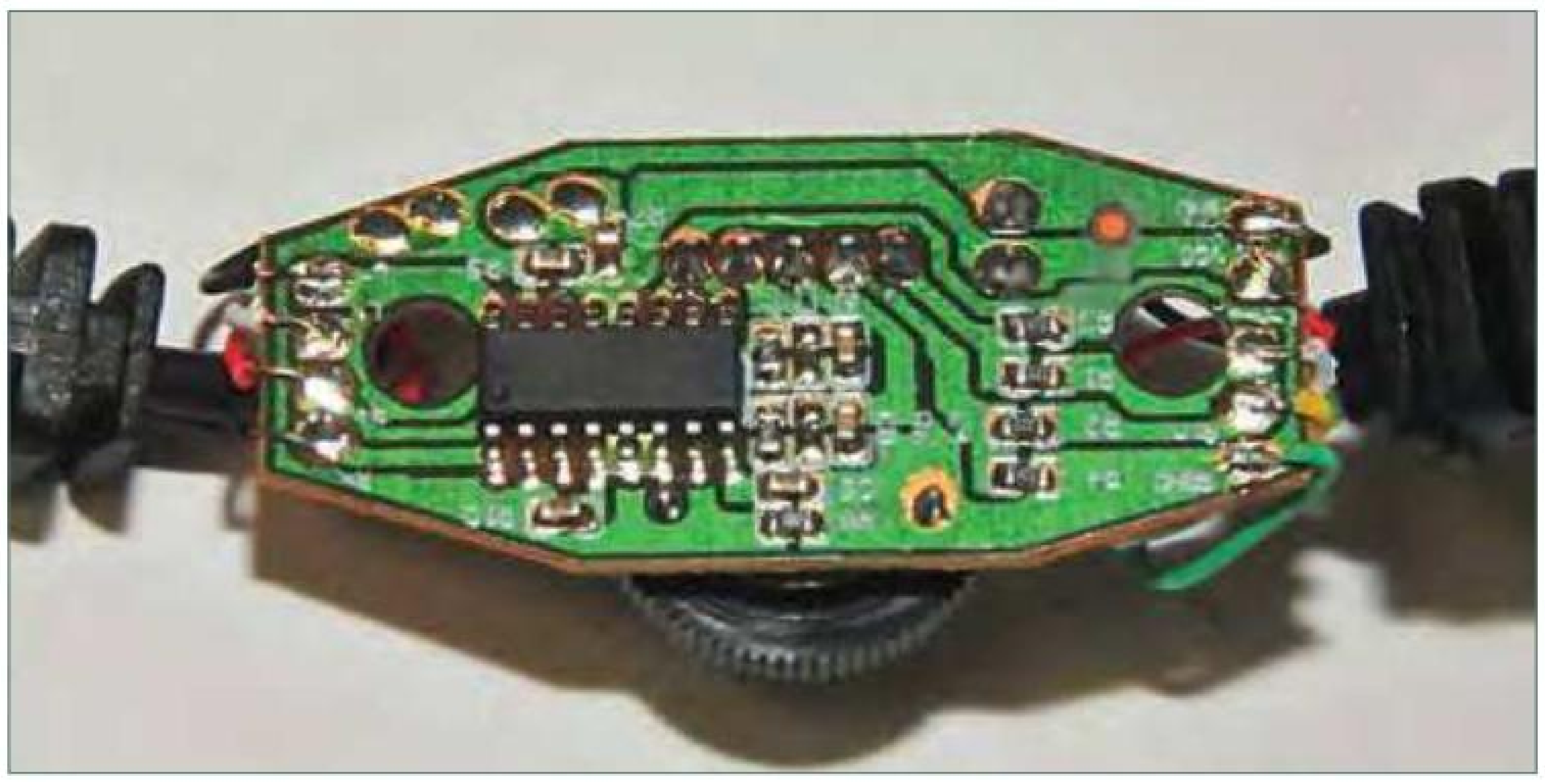
The data sheet for the LTK 5206 amplifier appears to be available only in Chinese, but the specification graphs and tables are shown with English annotation. On a 5V supply, peak power of the chip is 3.2W per channel into a 4Ω load – but that's at 10% distortion. However, at 1W output power, distortion is only 0.05% and at 2W, only 0.2%. Driven from an iPhone headphone output set to full volume, and with the audio amplifier also at full volume, distortion was minimal – so with the amplifier driven in this way, a maximum output is likely only a very few watts – plenty loud enough when you're as close to the speakers as a typical laptop user would be.

The speaker drivers each have a nominal diameter of 50mm and use a generous roll surround. The cone comprises what appears to be an aluminium diaphragm. The magnet is large – these are nothing like cheap 2-inch transistor radio speakers of the past.

Designing the speaker enclosures

If you wire up the speaker cables to the bare (boxless) drivers, connect an audio input (eg, your phone or laptop)

The kit comprises two small speakers, an audio amplifier with volume control, a USB power supply cable and a 3.5mm stereo plug to connect to the audio source. (Image courtesy of Banggood)



The tiny audio amplifier uses the LTK 5206 chip and is capable of 2W per channel output at low distortion. Note the volume dial underneath the PCB.

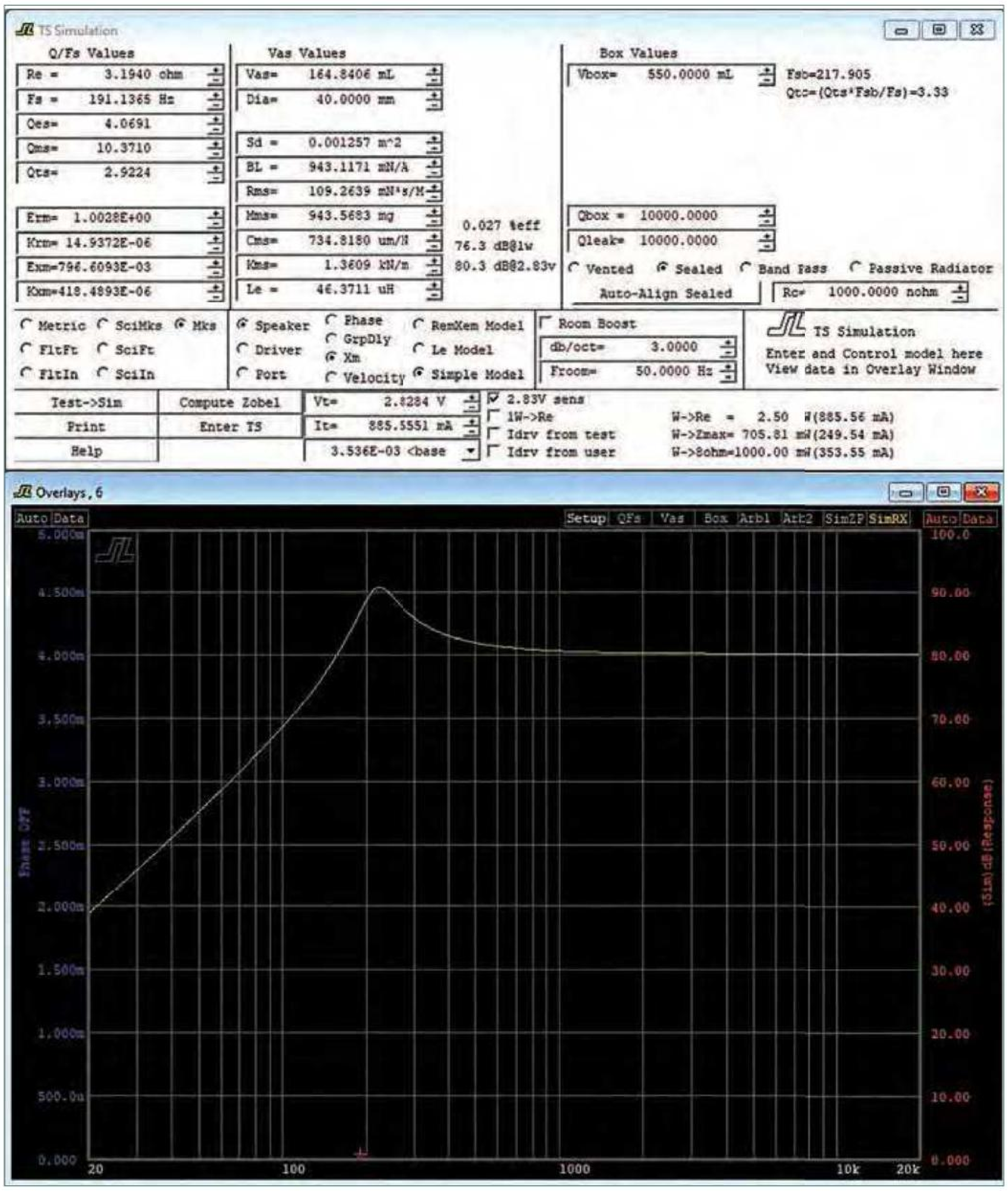
and power up the system, it will sound terrible – tinny and thin. But why?

What happens with bare drivers is that when the speaker cone moves forward, rather than creating an effective pressure wave in the air, the air simply flows around the edges of the driver's frame to fill the rarefaction (low pressure) created behind the driver. When the cone moves in the other direction, so does the airflow. To create good quality sound, especially at low frequencies (bass), the front and rear pressure waves need to be separated so that this cancelling effect cannot occur. The easiest way to do this is to place the driver in a sealed box. (Note that if the phase of the rear sound waves can be reversed, they can then be used to reinforce the front sound waves. This phase change is effected by using a tuned port enclosure.)

Testing of the speaker drivers was carried out using Smith and Larsen's Woofer Tester 2. This combination of hardware and software allows the measurement of what are called the 'Thiele-Small' specifications. These are much more complex specifications than power handling and impedance – often the only two specs supplied with low-cost speakers like these. Having the measured Thiele-Small speaker parameters available then allows different enclosure designs to be modelled.

I modelled ported and sealed enclosure designs. This modelling showed that a sealed enclosure was likely to give much better results than a ported design. Fortunately, this makes it easier to construct a suitable enclosure. In fact, a sealed enclosure with an internal volume anywhere from about 0.5 – 1 litre appeared to work well.

The modelled frequency response showed a lift from about 800Hz downwards, peaking at about 10dB at just over 200Hz. Now, if you were designing Hi-Fi speakers, you'd never want this – you'd have boomy one-note bass. And not very deep bass at that. However, with such small drivers, bass response was always going to be a struggle and so a lift in output here is, in practical terms, likely to give a more natural sound.


TS Simulation

Q/Fs Values
Re = 3.1940 ohm
Fs = 191.1365 Hz
Qes= 4.0691
Qms= 10.3710
Qts= 2.9224
Erm= 1.0028E+00
Krm= 14.9372E-06
Exm=796.6093E-03
Kxm=418.4893E-06

Vas Values
Vas= 164.8406 mL
Dia= 40.0000 mm
Sd = 0.001257 m^2
BL = 943.1171 mN/A
Rms= 109.2639 mN*s/M
Mms= 943.5683 mg
Cms= 734.8180 um/N
Kms= 1.3609 kN/m
Le = 46.3711 uH

0.027 %eff
76.3 dB@1w
80.3 dB@2.83v

Box Values
Vbox= 550.0000 mL
Fsb=217.905
Qtc=(Qts*Fsb/Fs)=3.33
Qbox = 10000.0000
Qleak= 10000.0000
○ Vented ● Sealed ○ Band Pass ○ Passive Radiator
Rc= 1000.0000 mohm

○ Metric ○ SciMks ● Mks
○ FltFt ○ SciFt
○ FltIn ○ SciIn
● Speaker ○ Driver ○ Port
○ Phase ○ GrpDly ● Xm ○ Velocity
○ RemXem Model ○ Le Model ● Simple Model
☐ Room Boost
db/oct= 3.0000
Froom= 50.0000 Hz

TS Simulation
Enter and Control model here
View data in Overlay Window

Vt= 2.8284 V
It= 885.5551 mA
3.536E-03 <base
☑ 2.83V sens
☐ 1W->Re
☐ Idrv from test
☐ Idrv from user
W->Re = 2.50 W(885.56 mA)
W->Zmax= 705.81 mW(249.54 mA)
W->8ohm=1000.00 mW(353.55 mA)

Overlays, 6

Woofer Tester 2 was used to measure the driver specifications and then model different enclosures. Here is the predicted frequency response of the 0.55-litre enclosure used in the final design. Note the rise in response around 200Hz, giving increased bass from what is a very small speaker system.

Given that the modelled response varied little with enclosure volumes from 0.5 to 1 litres, the smaller enclosure volume was selected, so giving a reduced desk footprint.

Choosing the enclosures

If you've ever tried to make speaker enclosures, you'll know it's a lot of work – and very small enclosures are even trickier because they're viewed in close-up most of the time. So, in this project I didn't make the speaker enclosures. Instead, I went to the local craft and cheapo stores (aka dollar/pound stores, penny shops) to find something prebuilt that would be suitable. The criteria were:

- Internal volume approx 0.5 litres (~50% bigger than a soft drinks can)
- A flat face that's easy to cut, allowing a hole for the speaker driver
- Resonantly 'dead' (when tapped it didn't ring)
- Surface/texture that's easily sealed
- Cheap!

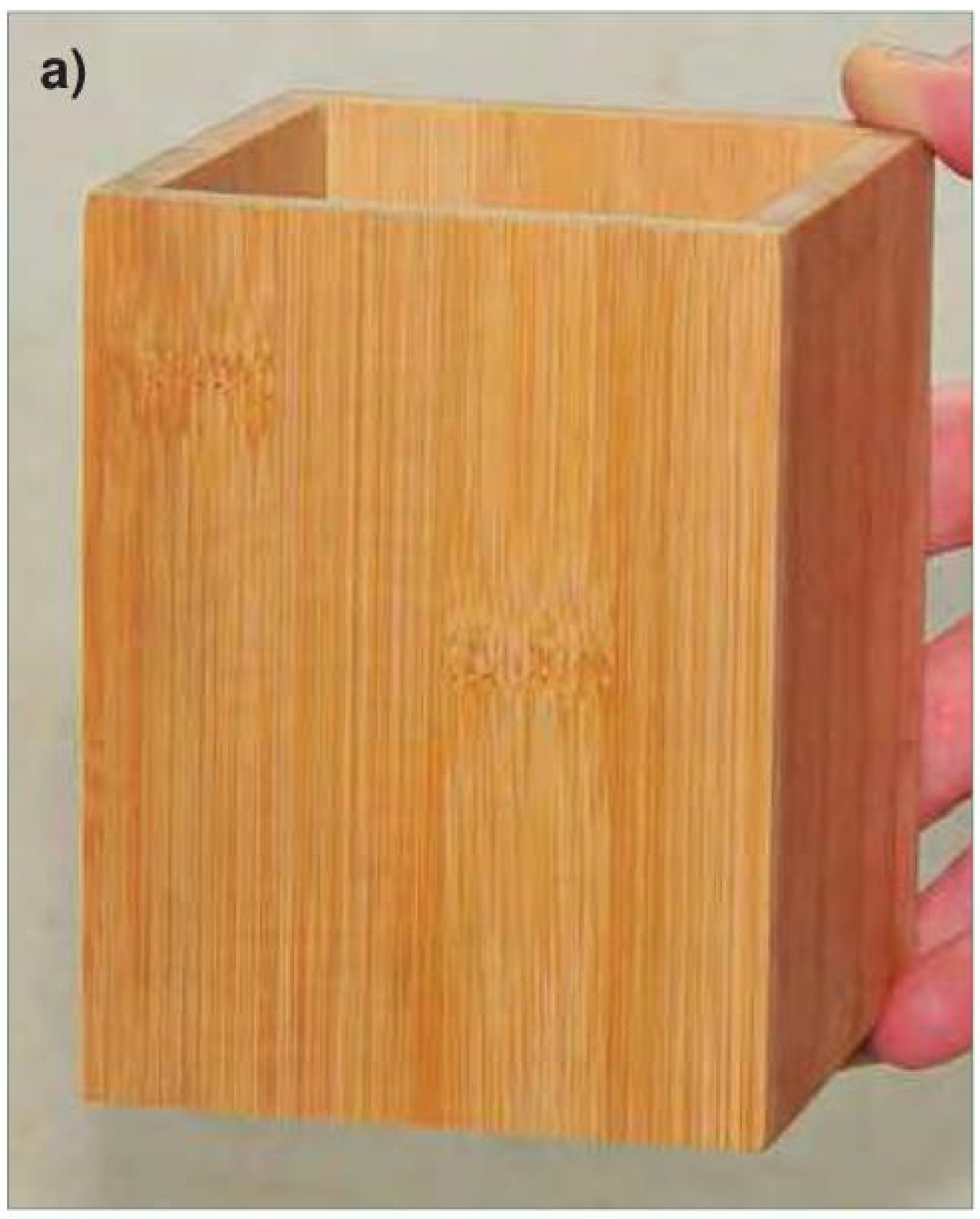
The most suitable item proved to be a bamboo open-ended wooden box – a bit like a large square drinking mug. Sold as a cutlery holder, it had external dimensions of 90 x 90 x 120mm. Internal volume was 0.55 litres and the cost was just £2 each. The bottom panel was recessed by 5mm, making it the ideal location to mount the driver. The other (open) end could be easily sealed with a square piece of plywood cut to size and glued in place.

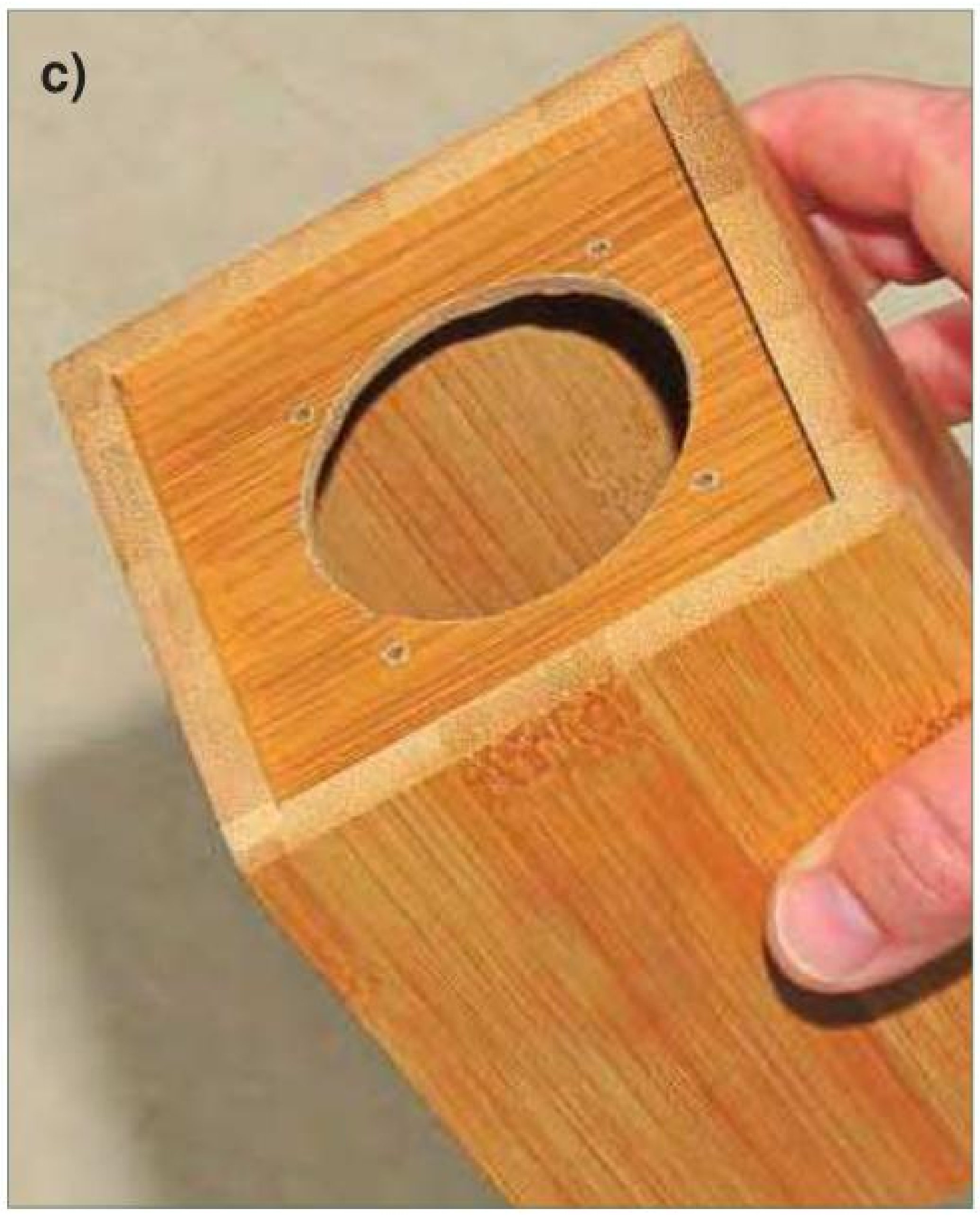
Other items I looked at that would be suitable included toothbrush mugs made from resin, the large cups in which toilet brushes sit, unpainted 'craft' boxes and wooden pencil holders.

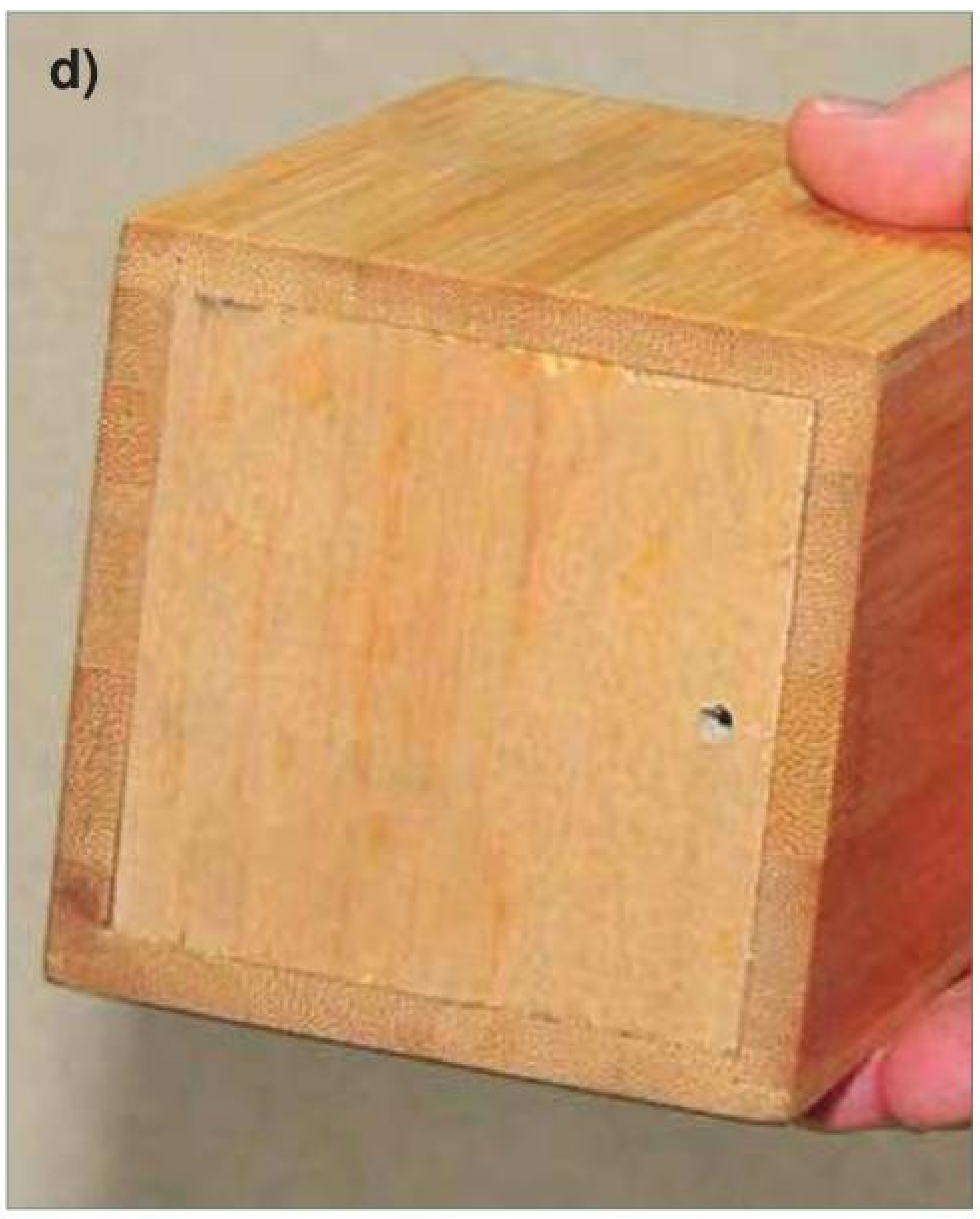
Building the speaker enclosures

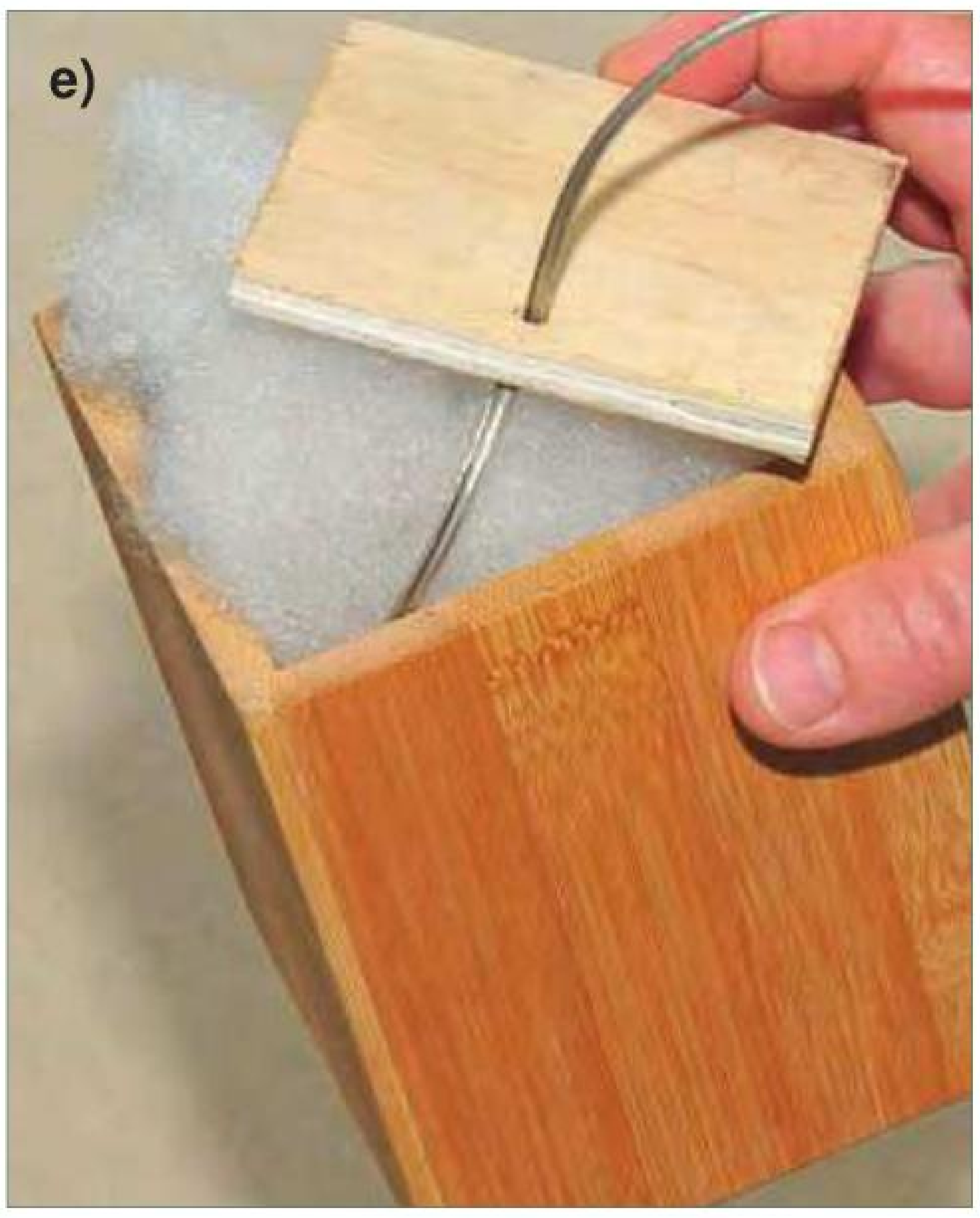
The hole in the base panel was cut first. The hole needs to be exactly 50mm in diameter – this is important as too small a hole and the driver won't sit flush, and too large a hole and there will be gaps around the frame and it will be hard to screw the driver into place. I cut the hole with a powered holesaw but if you don't have one of these, take the following approach. First, accurately mark the circle, then drill many closely spaced small holes around the inside of the circle until the middle piece can be pushed out. Use a file and sandpaper on the jagged edge to fine tune the final shape of the hole.

The new rear panel can be cut from any acoustically dead, stiff material. I used plywood that was 7mm thick. This panel should fit within the box, sitting flush with the end. It can be hard to precisely cut such a piece, but in fact it doesn't have to be accurately sized – any small gaps can be filled by glue when you permanently attach it. (But at this stage don't glue the panel into place). Drill a small hole in this panel for the speaker cable.









a) The speaker enclosures were made from these bamboo boxes. They are sold as cutlery holders and cost only £2 each. Any similar box with an internal volume of about half a litre can be used.

b) The boxes featured a recessed bottom panel – the speaker driver was placed here.

c) The hole for the speaker was cut with a holesaw. Note the pilot holes for the speaker securing screws.

d) A new bottom panel was made from 7mm-thick plywood. The small hole is for the speaker cable.

e) Filling the enclosures with fluffy polyester material noticeably improves the quality of the sound.

Initial tests

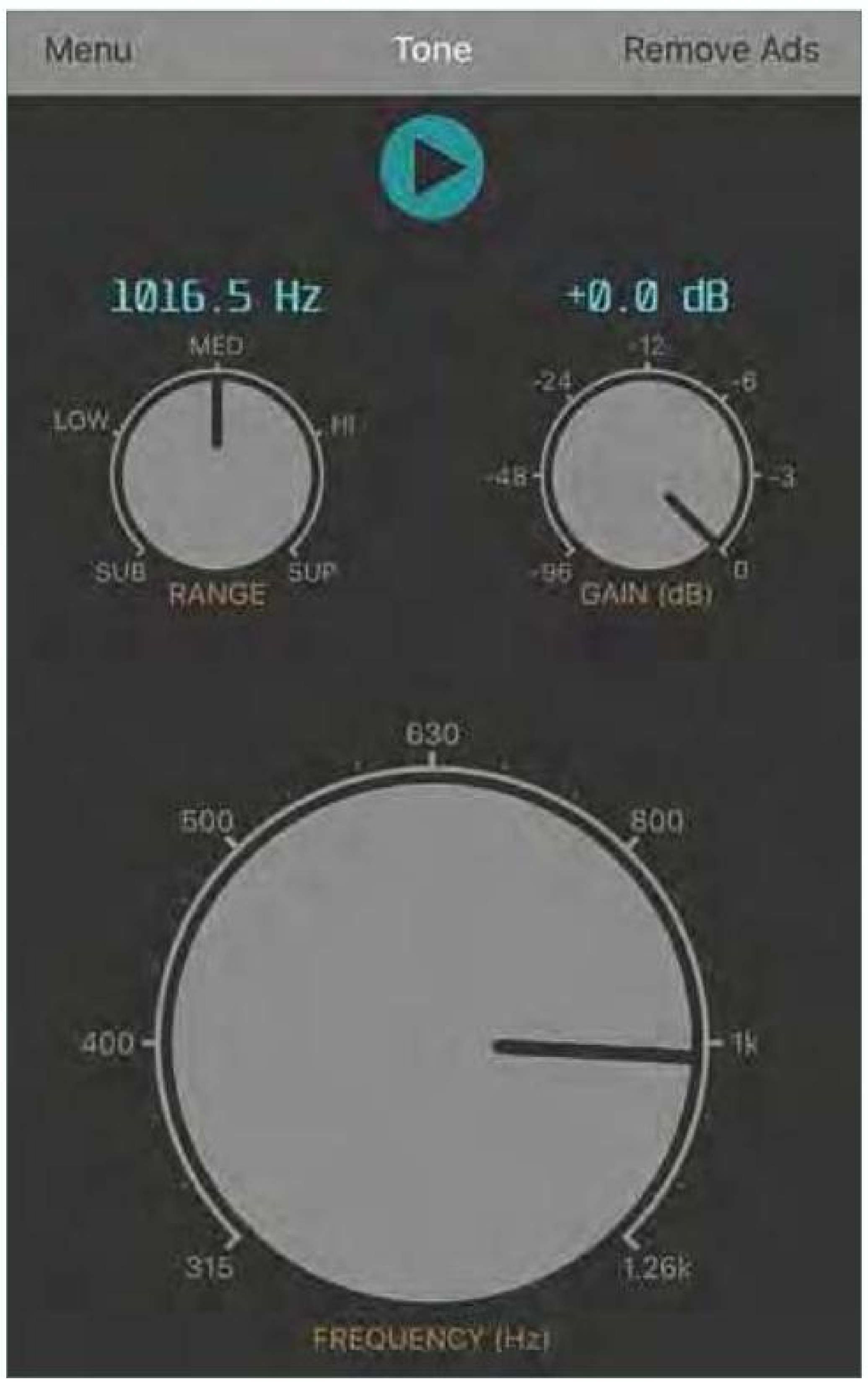
The next step is to do some initial tests. Feed the speaker cables through the bottom panel holes and then the main speaker openings, soldering the leads to the speakers. Note the required polarity – in each case, the black wires are negative. Screw the speakers into place – you'll need to supply some small self-tapping screws and you should first drill pilot holes to avoid the wood splintering. Just push the rear panel into place for this testing.

Provide USB power and an audio source and listen very carefully to how the system now sounds. The audio quality should be radically better than

The speaker drivers are 50mm in diameter. They use roll surrounds and what 'appear' to be aluminium cones. Driver impedance is 4Ω impedance, and they're rated at 3W.

when you listened with the speaker drivers bare on the bench. In fact, I'd be surprised if you weren't rather amazed at how good this incredibly cheap system already sounds. But – and this also depends on the enclosure materials – you may hear a 'hollow ringing', a bit like the speaker is working in a concrete pipe, but not that bad. This is due to the sound waves inside the enclosure bouncing back and forth and even coming back out through the cone of the speaker.

To absorb these reflecting vibrations, we need to place some fluffy material inside the enclosure. Polyester 'wool' is cheap and readily available – it's sold for use inside stuffed toys, quilts and even for use in aquarium filters. Some people may have access to real sheep's wool – you can definitely use that too. Basically, anything that resembles this material can be used – even a small piece of fibreglass insulation. Place this material inside the enclosures – just enough to loosely fill them, but don't stuff the enclosures tightly.



A free audio frequency generator app can be used to test the speakers. It's particularly effective in finding unwanted resonances – for example, those caused by a loose speaker. This iPhone app is called Tone.

Listen again and you should hear an immediate improvement in the quality of the sound.

Tone generation

I'll now assume that you are using your PC or phone as the audio source. Access a web page or download an app that gives you an audio frequency generator – there are plenty available. For example, the Tone app for the iPhone, or use these more general web-based ones on your PC: **https://onlinetonegenerator.com** or **www.szynalski.com/tone-generator**

These will allow you to generate tones from 20Hz – 20kHz, sweeping through them in a sound that varies from the deepest bass to the highest treble. Now test the speakers with such a frequency sweep. *Ensure that you keep the volume low* – it's easy to damage a speaker with over-loud sinewave signals (read and note the excellent advice on the **szynalski.com** web page).

When doing the frequency sweep, listen for resonances. A resonance is a frequency at which the system, for a constant electrical power input, has a much greater audio output. You will hear a resonant peak around 200Hz (as predicted in the modelling) but listen for other odd peaks. For example, when I did this test, I found the speaker frame vibrating fiercely at one frequency. Slightly loosening the nearest mounting screw fixed that. If your enclosure's rear panel is too loose, you may well hear air leaks past the gaps – a good demonstration of why in the final build, a sealed enclosure does need to be completely sealed.

Finishing off and tweaks

Once the resonances are fixed, you can now glue the rear panel into place and seal the hole through which the speaker cable passes. Some rubber feet stuck to the bottom of the enclosures will prevent scratching of furniture surfaces and give clearance for the cable.

At this stage you may well be quite happy with the sound – and that's fine. But I wondered if two further improvements couldn't be made. The first was that the treble was just a bit too strong – often picked out as singer's sibilance on some tracks. The other was that I thought it would be good to give the speakers less directionality – that is, make them more omni-directional. Back to the craft shop I went to pick up something I'd seen earlier – some low-cost polystyrene balls of varying diameters (£2 the lot). And, having a pretty good idea of what I wanted to do with them, some small diameter, coloured dowels (£1 a pack).

I then oriented the speaker enclosures vertically and held the different diameter polystyrene balls above the drivers while listening to the differing frequency responses. Held too close, the treble and 'presence' decreased too much; held too far away there was no difference in the sound. But positioned at just the right distance (about 20mm from the cone to the underside of the ball) the 60mm diameter balls reduced the sibilance without degrading other aspects of the response. I then sharpened the dowels and pushed them into the balls until the

Want to take your speaker designs to the next level?

In our May 2017 issue, Julian Edgar reviewed the Smith and Larsen Audio Woofer Tester 2 hardware and software package mentioned in this article.

If you want to design, tweak and experiment with all aspects of speaker design then this is a great product to consider.

EPE product review

Smith & Larson Audio

Woofer Tester 2

by Julian Edgar

Find speaker specs in minutes! Directly measures Thiele Small speaker specifications, and design effective speaker enclosures for drivers that don't normally have proper specs available.

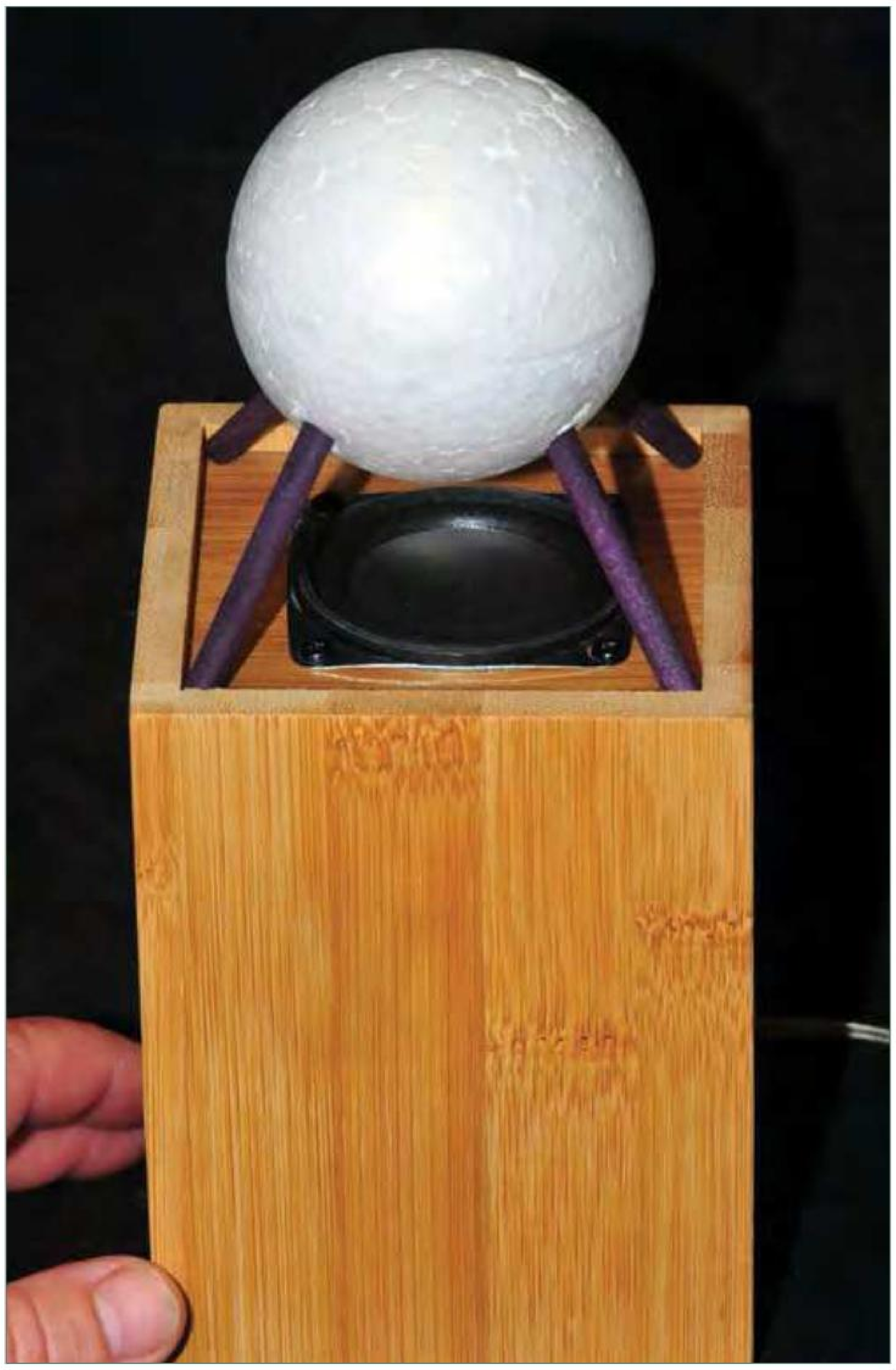
If you're into sound systems, you'll be well aware of the famed Thiele Small speaker parameters that are especially important when designing woofers and subwoofers. These parameters are the speaker specs that you plug into software (or an on-line calculator) to allow you to design the speaker box. That box design includes aspects such as internal volume and length, and the diameter of any ports.

Without the Thiele Small (abbreviated to TS) specs of the driver, you're just guessing the box design – and the chances are overwhelming that your guess will be less than optimal.

the TS specs are measured. Do some more testing (eg, weighting the cone a known amount) and the rest of the important specs are there in front of you – it's that easy!

Furthermore, the Woofer Tester 2 also includes a box design tool so you can develop the enclosure without

Fig.2. Directly measuring Thiele Small parameters allows you to



The speakers use a foam sphere positioned a critical distance above the speaker driver. This gives better sound dispersal and helps absorb some of the treble that can otherewise be peaky.

balls were supported at the right height. And, with the balls at this height, the directionality of the speakers was also much reduced – the sound now better fills the room, rather than apparently coming from two tiny speakers. I don't think the balls make a *dramatic* difference – it's perhaps 10-15% of the final sound – so they're very much an option, but a very cheap option at that (And the look kinda cool!)

Note that I chose to leave the speakers in the colours the parts came in, but you could of course paint each component – identical colours or a variety.

The results

No one who listened to the final system could believe the results for the amount of money that I spent – and that includes people who have worked on audiophile-level, exotic speakers. For a desk-top system there's plenty of volume and the speakers work surprisingly well in reproducing intricate details.

If you want lots of bass, add a subwoofer (or even just a woofer) that works from 200Hz downwards. But if you just want quiet music while you're working, or to be able to watch YouTube videos while still understanding poorly recorded audio that laptop speakers make unintelligible, this system will do it.

And, if you're venturing into home speaker building, this is the cheapest toe-in-the-water I've ever seen. It's an excellent way to experiment and learn about the basics of speaker construction. You can tweak and experiment, safe in the knowledge that you're not risking expensive parts or days of fine woodwork.

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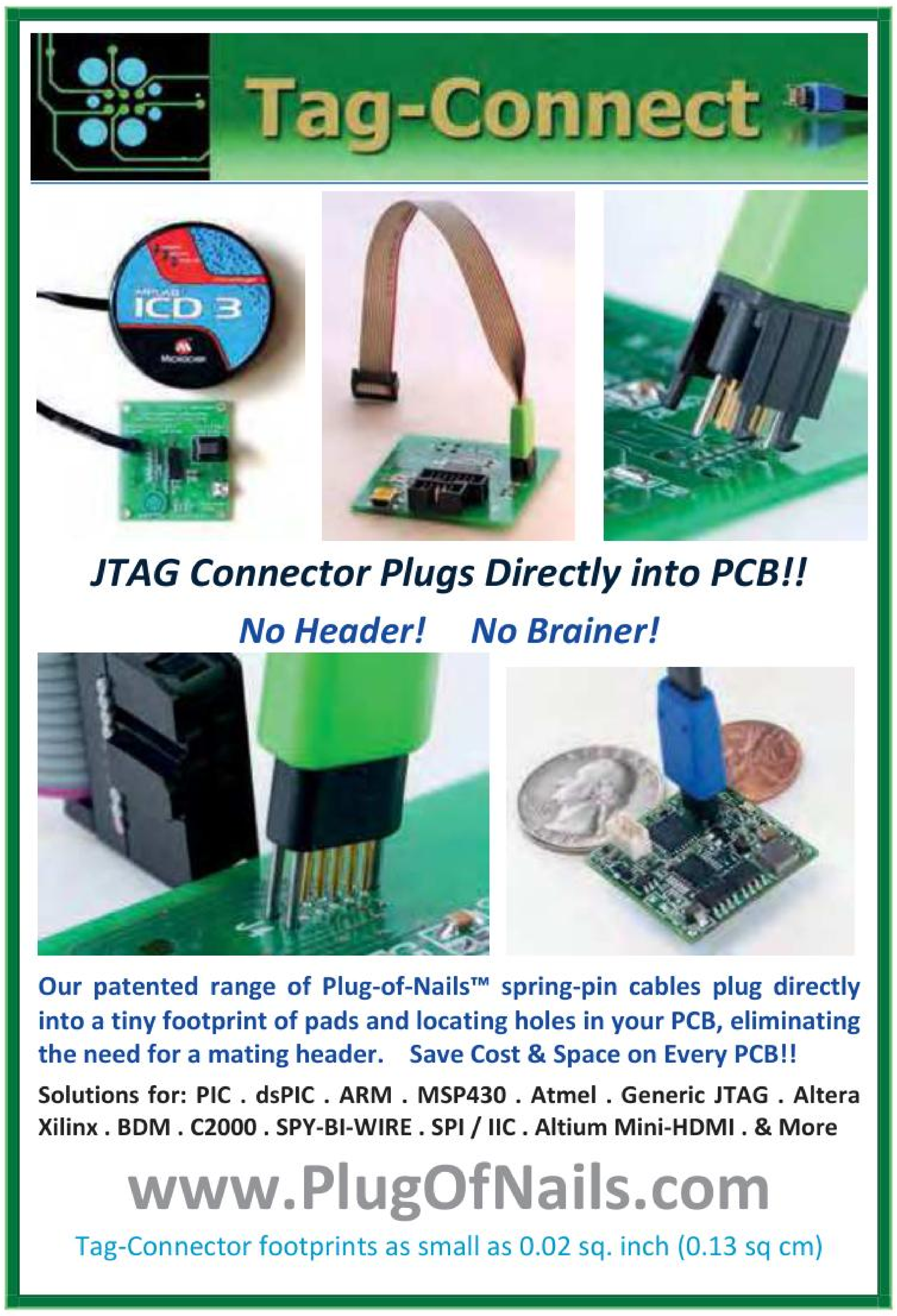

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PROJECT	CODE	PRICE
MARCH 2022		
Mini Isolated Serial Link	24102211	£5.95
Busy Loo Indicator	16112201	£5.95
Analogue Vocoder – Band-pass filter board	AO1-MAR22	9.95
Analogue Vocoder – HP/LP filter board	AO2-MAR22	9.95
FEBRUARY 2022		
Arduino-based Power Supply	18106201	9.95
Battery Monitor Logger	11106201	10.95
Electronic Wind Chimes	23011201	10.95
Analogue Vocoder – Driver Amplifier	AO-FEB22	8.95
JANUARY 2022		
Vintage battery Radio Li-ion Power Supply	11111201	9.95
MiniHeart: A Miniature Heartbeat Simulator	01109201	8.95
DECEMBER 2021		
AM/FM/SW Digital Receiver	CSE200902A	13.95
Balanced Input and Attenuator for USB CODEC	01106202	11.95
NOVEMBER 2021		
Dual Battery Lifesaver	11111202	£6.95
OCTOBER 2021		
Mini Wi-Fi LCD BackPack	24106201	£8.95
SEPTEMBER 2021		
USB SuperCodec PCB	01106201	£14.95
Audio DDS Oscillator PCB	01110201	£5.95
Audio DDS Oscillator rotary encoder	01110201-ENC	6.95
Programming Adaptor Board for Audio DDS Oscillator	01110202	£5.95
High-power Ultrasonic Cleaner main PCB	04105201	£14.95
High-power Ultrasonic Cleaner front-panel PCB	04105202	
Night Keeper Lighthouse PCB	08110201	£5.95
AUGUST 2021		
Ol' Timer PCB	19104201	£11.95
Ol' Timer 8x8 RGB LED module using WS2812B	19104201-88	£8.95
Ol' Timer set of acrylic case pieces and spacer	19104201-ACR	£8.75
Ol' Timer DS3231 RTC IC wide SOIC-16	19104201-RTC	£5.95
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Switchmode 78xx regulators ***(PACK of 5!)***	18105201	£7.95
Cool Beans SMAD display	CB-AUG21	£11.95
JULY 2021		
ATtiny816 Breakout / Dev Board with Capacitive Touch	24110181	£9.75
IR Remote Control Assistant (Jaycar version)	15005201	£8.95
IR Remote Control Assistant (Altronics version)	15005202	£8.95
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Microphone Preamplifier	AO-JUL21	£11.95
JUNE 2021		
Roadies' Test Signal Generator (surface-mount version)	01005201	£8.95
Roadies' Test Signal Generator (through-hole version)	01005202	£9.95
Touchscreen Wide-range RCL Box (Resistor module)	04104201	£18.95
Touchscreen Wide-range RCL Box (Ind/Cap module)	04104202	
KickStart Part 3 – Gyrator-based Audio Filter	KS3-2021	£7.95
MAY 2021		
7-Band Equaliser (Mono)	01104201	£8.95
7-Band Equaliser (Stereo)	01104202	£10.95
Car Altimeter	05105201	£7.95

PROJECT	CODE	PRICE
APRIL 2021		
Reflow Oven – DSP Active Crossover (CPU)	01106193	£19.95
Reflow Oven – DSP Active Crossover (Front panel)	01106195	
Reflow Oven – DSP Active Crossover (LCD)	01106196	
Frequency Reference Signal Distributor	CSE200103	£8.95
MARCH 2021		
Nutube Guitar Effects Pedal	01102201	£12.95
Programmable Thermal Regulator (Peltier Interface)	21109181	£18.95
Programmable Thermal Regulator (Peltier Driver)	21109182	
Tunable HF Preamp	CSE190502	£8.95
FEBRUARY 2021		
4G Remote Monitoring	27111191	£9.95
JANUARY 2021		
Nutube Valve Preamplifier	01112191	£12.95
Arduino DCC Controller	09207181	£10.95
DECEMBER 2020		
Pseudo-Random Sequence Generator	16106191	£7.95
Clever Charger	14107191	£11.95
PE Theremin Amplifier	AO-1220-01	£8.95
NOVEMBER 2020		
LED Christmas Tree (1 off)	16107181-1	£6.95
LED Christmas Tree (4 off)	16107181-2	£14.95
LED Christmas Tree (12 off)	16107181-3	£24.95
LED Christmas Tree (20 off)	16107181-4	£34.95
USB/SPI Interface Board	16107182	£5.95
45V/8A Power Supply PCB *plus* acrylic spacer	18111181	£14.95
45V/8A Power Supply front panel five-way display bezel	18111181-BZ	£3.95
Five-way LCD Panel Meter/Display	18111182	£7.95
OCTOBER 2020		
Digital Audio Millivoltmeter	04108191	£9.95
Precision Signal Amplifier	04107191	£7.95
SEPTEMBER 2020		
PE Theremin PSU	AO-0920-01	£5.95
PE Theremin PSU transformer	AO-0920-02	£7.95
Micromite Explore-28	07108191	£6.95
Ultrabrite LED Driver	16109191	£6.95
AUGUST 2020		
Micromite LCD BackPack V3	07106191	£9.95
Steering Wheel Audio Button to Infrared Adaptor	05105191	£7.95
JULY 2020		
AM/FM/CW Scanning HF/VHF RF Signal Generator	04106191	£13.95
Speech Synthesiser with the Raspberry Pi Zero	01106191	£5.95
PE Mini-organ PCB	AO-0720-01	£14.95
PE Mini-organ selected parts	AO-0720-02	£8.95
High-current Solid-state 12V Battery Isolator – control	05106191	£6.95
High-current Solid-state 12V Battery Isolator FET (2oz)	05106192	£9.95
JUNE 2020		
Arduino breakout board – 3.5-inch LCD Display	24111181	£6.95
Six-input Audio Selector main board	01110191	£10.95
Six-input Audio Selector switch panel board	01110192	

PCBs for most recent *PE*/*EPE* constructional projects are available. From the July 2013 issue onwards, PCBs with eight-digit codes have silk screen overlays and, where applicable, are double-sided, have plated-through holes, and solder mask. They are similar to photos in the project articles. Earlier PCBs are likely to be more basic and may not include silk screen overlay, be single-sided, lack plated-through holes and solder mask.

Always check price and availability in the latest issue or online. A large number of older boards are listed for ordering on our website.

In most cases we do not supply kits or components for our projects. For older projects it is important to check the availability of all components before purchasing PCBs.

Back issues of articles are available – see Back Issues page for details.

Double-sided | plated-through holes | solder mask

PROJECT	CODE	PRICE
MAY 2020		
Ultra-low-distortion Preamplifier Input Selector	01111112	£11.25
Ultra-low-distortion Preamplifier pushbutton Input Selector	01111113	
Universal Regulator	18103111	£7.95
433MHz Wireless Data Repeater	15004191	£8.50
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iCEstick VGA Terminal	02103191	£5.95
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For editorial contact details see page 7.

Next Month – in the April issue

SILICON CHIP Digital FX
POWER
IN
OUT
Effects input level
Dry mix
Effects mix
Output level
Effects parameters
PATCH

Digital FX Unit – Part 1

Make like a pro muso with this Digital FX (Effects) Unit. It will produce unique sounds when connected to a variety of instruments, like an electric guitar, bass, violin or cello, even the output of a microphone preamp or within the effects loop of an amplifier or mixer.

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64-key Arduino MIDI matrix – Part 1

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KickStart – Part 8: Introducing the Raspberry Pi Pico

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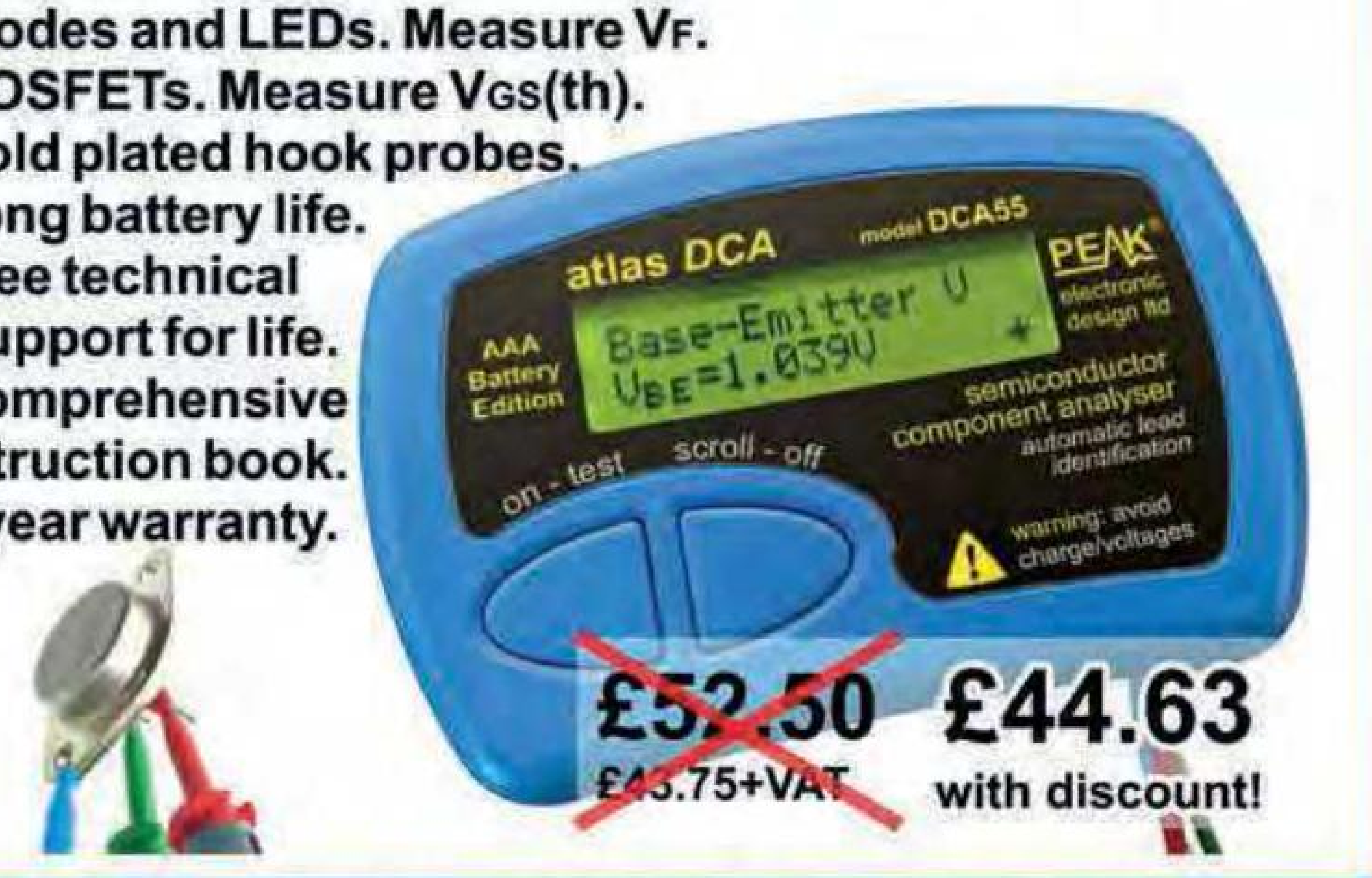
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